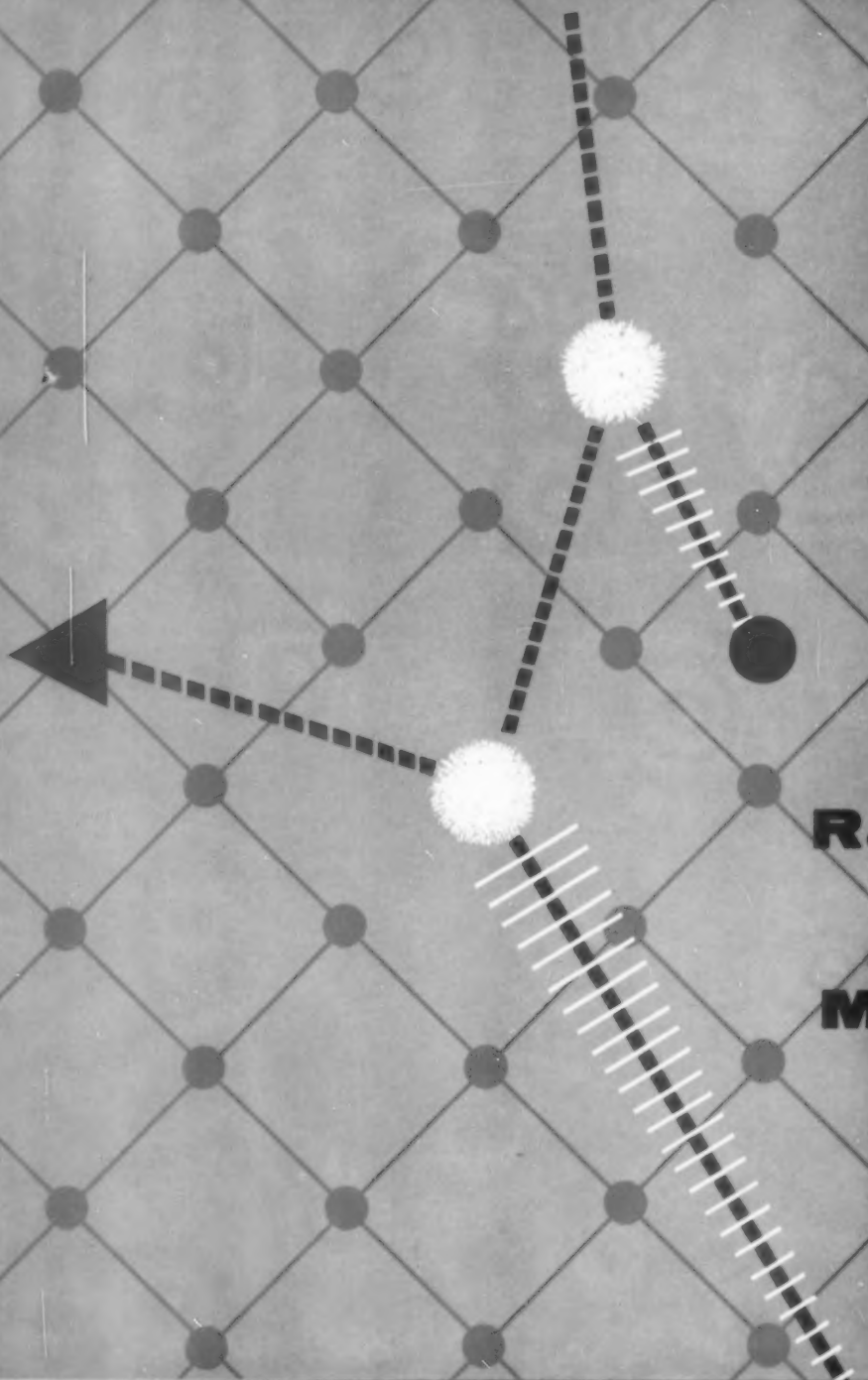
September 1956

A McGraw-Hill Publication • Seventy Five Cents

NUCLEONICS

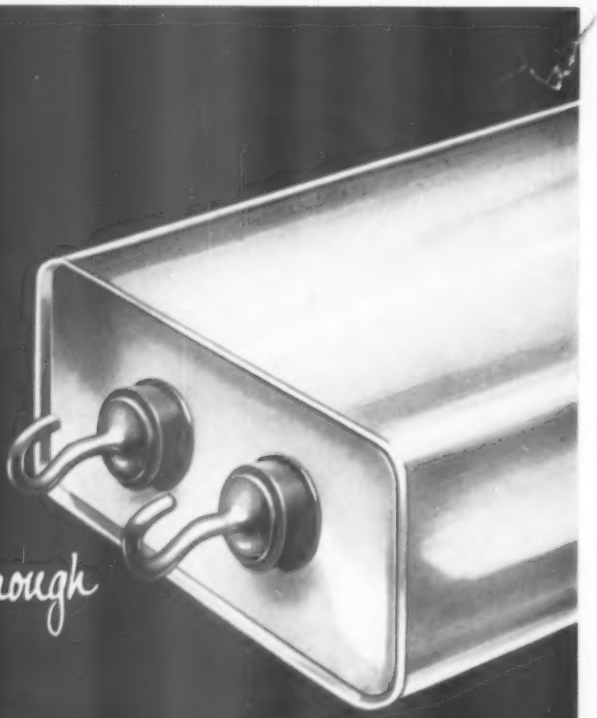
ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



How Radiation Affects Materials

see page 53

IRC®
Hermetic Sealing Terminals



Only the signal ever gets through

THE SEAL STARTS AIR-TIGHT

IRC Type LT Hermetic Terminals more than meet military requirements and commercial standards because of their inherently superior design. First of all, they are a solder seal type. And the terminals are separated from the seal ring by a specially-compounded plastic (polymonochlorotrifluoroethylene) which is bonded to metal surfaces by an exclusive IRC process. Even with rough handling, you're sure of getting the best possible seal from the start.

THE SEAL STAYS AIR-TIGHT

Not only is the special plastic body a superior insulating material, but it also keeps the seal air-tight under demanding service conditions. Because of its high resistance to thermal shock, it withstands higher operating temperatures (—70°C. to +150°C. continuous or +190°C. intermittent). Furthermore, its zero water absorption eliminates the effects of high humidity. It is also chemically inert to organic solvents, acids, alkalies, oils, fumes, and other atmospheres.

Type LT
HERMETIC SEALING
TERMINALS
1, 2, 3 & 5 KILOVOLT SIZES
6 LEAD TYPES

THE TERMINAL TAKES HEAVY LOADING

IRC Type LT Hermetic Terminals give superior electrical performance. They're made to withstand voltages as high as 5,000 volts and they eliminate the problems of low corona breakdown voltage and excessive electrolysis under high DC voltage. Available in a choice of leads—phosphor bronze, copper, and brass.

INTERNATIONAL RESISTANCE CO.

Dept. 344, 401 N. Broad St., Phila. 8, Pa.

In Canada: International Resistance Co., Ltd., Toronto, Licensee

Send me Hermetic Terminal Bulletin LT-1.

NAME.....

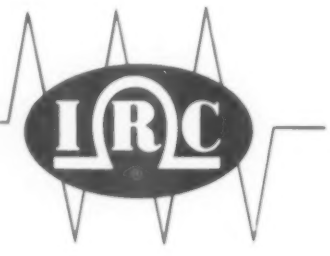
COMPANY.....

ADDRESS.....

CITY..... STATE.....

Insulated Composition Resistors • Deposited and Boron Carbon Precistors • Power Resistors • Voltmeter Multipliers • Ultra HF and Hi-Voltage Resistors.

Wherever the Circuit Says



Low Wattage Wire Wounds • Resistance Strips and Discs • Selenium Rectifiers and Diodes • Hermetic Sealing Terminals • Insulated Chokes • Precision Wire Wounds • Potentiometers.

NUCLEONICS

SEPTEMBER • 1956

Vol. 14, No. 9

H. W. MATEER, Publisher

JEROME D. LUNTZ, Editor

JAMES J. DUTTON, Managing Editor

Daniel I. Cooper, Associate Editor

Thomas L. Cramer, Assistant Editor

John E. Kenton, News Editor

R. Hobart Ellis, Jr., Assistant Editor

Nancy Purves Case, Production Editor

Carol Williamson, Editorial Assistant

Patricia Simons, Editorial Assistant

Harry Phillips, Art Director

Roy Thompsen, Assistant Art Director

G. B. Bryant, Jr., Chief, Washington Office

Craig Richter, Washington Office

John Wilhelm, Chief, World News Staff

London—W. J. Coughlin, J. Tunstall

Paris—Robert E. Farrell

Bonn—Gerald W. Schroder

Tokyo—Dan Kurzman

Rio de Janeiro—Peter Weaver

Mexico City—Jack Kearney

Melbourne—Alicja Grobtuch

Brussels—A. P. L. Gordon

Bombay—Sharokh Sabavala

Copenhagen—Else Balslev

Geneva—Ernest Hediger

Johannesburg—G. M. Thain

Rome—Diego Straniero

Stockholm—George Williamson

Vienna—F. H. Baer

KEITH HENNEY, Consulting Editor

WALLACE B. BLOOD, Manager

R. S. Quint, Buyers' Guide Manager

Frank H. Ward, Business Manager

Philip H. Hubbard, Jr., New York

Philip H. Hubbard, Jr., New England

James T. Hauptli, Philadelphia

C. D. Wardner, B. Winner, W. Luce, Chicago

Henry M. Shaw, Cleveland

T. H. Carmody, R. C. Alcorn, San Francisco

Carl W. Dysinger, Los Angeles

R. H. Powell, Atlanta

G. L. Jones, D. Billian, Dallas

Herbert Lagler, London

J. E. Blackburn, Jr., Director of Circulation

A Special Report:

How Radiation Affects Materials ... 53

Basic Mechanisms ... 54

Engineering Use of Damage Data ... 58

Damaging Effects of Radiation:

On Solid Reactor Materials ... 63

On Electronic Components ... 66

On Plastics and Elastomers ... 70

On Chemical Materials ... 75

Beneficial Effects of Radiation:

On Polymers ... 82

On Metals ... 86

Fission-Product Buildup in Enriched Thermal Reactors ... 89
ROBERT W. DEUTSCH

Canadian Fuel Processing ... 92
W. M. CAMPBELL

Cheaper Ways to Make D_2O ... 97
PAUL HARTECK

Compact, Low-Cost Reactor Emphasizes Safety ... 100
A. T. BIEHL, *et al*

Japan Speeds Organization of Nuclear Program ... 104
CLARK GOODMAN

Second Atomic Trade Fair Ready to Open at Chicago ... 150

Cross Sections

A Gamma-Discriminating Beta Survey Meter ... 108
WALTER F. JOSEPH and RICHARD M. BOND

CONTENTS Continued on Next Page

About NUCLEONICS

One of the toughest—yet most rewarding—tasks of putting a journal such as this together is getting out "special reports" like the one on p. 53 of this issue. In our normal month-to-month effort, we have more than enough material on hand at the time editing is done so that we don't have to worry about being held up because authors don't meet writing deadlines.

But the very nature of a special report is that it is a collection of articles prepared by workers in the field, written to predetermined specs, and requested for submission by a very specific date. It's this last requirement that gives editors palpitations. We set our manuscript deadlines to give authors the greatest amount of writing time and to allow them to squeeze in the very latest data. In fact, the big table in the article by Harrington (p. 70) contains a great deal of data that was slipped into the table only several weeks before this issue appeared.

What really brings the aspirin out is sweating through seemingly routine clearances of papers. Although we have invariably gotten excellent cooperation on expediting clear-

NUCLEONICS

CONTENTS Continued

NUCLEONICS (with which is consolidated "Atomic Power" and "Atomic Engineering") September, 1956, Vol. 14, No. 9. Published monthly by the McGraw-Hill Publishing Co., Inc., Executive, Editorial, Advertising and Subscription Offices: McGraw-Hill Building, 330 West 42nd Street, N. Y. 36, N. Y. Publication Office, 212 East York St., York, Pa. Entered as second class matter December 17, 1947 in the Post Office at York, Pa., under the act of March 3, 1879. Copyright 1956 by McGraw-Hill Publishing Company, Inc. All rights reserved. Donald C. McGraw, President; Paul Montgomery, Executive Vice President; Joseph A. Gerardi, Executive Vice President and Treasurer; Hugh J. Kelly, Executive Vice President; John J. Cooke, Secretary; Nelson Bond, Executive Vice President, Publications Division; Ralph B. Smith, Vice President and Editorial Director; Joseph H. Allen, Vice President and Director of Advertising Sales; J. E. Blackburn, Jr., Vice President and Circulation Director. **FOR SUBSCRIPTIONS**, write to Nucleonics-Subscription Service, 330 West 42nd Street, New York 36, N. Y. **Orders must indicate company and position.** Allow one month for change of address. Price per copy $.75. Subscription rates: United States and U. S. Possessions $8 for 1 year, $12 for 2 years, $16 for 3 years. Canada $10 for 1 year, $16 for 2 years, $20 for 3 years. Other Western Hemisphere countries and the Philippines $10 for 1 year, $16 for 2 years, $20 for 3 years. All other countries $15 for 1 year, $25 for 2 years, $30 for 3 years. Member of ABC. Member of ABP.

Apparatus for Injecting Radioactive Colloids . . . 110
J. P. VIGNE, R. SANTELLI, and J. FOUNDARAI

Clamp for Handling Radioactive Liquids . . . 112
A. SCHWEBEL

Resolution of Two-Component Decay Data . . . 112
E. C. FREILING AND L. R. BUNNEY

Instruments for Monitoring Tritium in the Atmosphere . . . 114
B. C. EUTSLER, *et al*

Electron Accelerator Used for Producing Neutrons . . . 118
A. J. MOSES and J. SALDICK

Scintillation Counter for Beta-Ray Dosimetry . . . 120
PAUL N. GOODWIN

Detection of S^{35} and Ca^{45} with a Plastic Scintillator . . . 124
MARVIN L. MITCHELL, LOUIS A. SARKES and ELIZABETH S. DELL

Analysis of U and Th Minerals by Alpha Spectrum . . . 126
U. FACCHINI, M. FORTE, A. MALVICINI, and T. ROSSINI

High-Pressure Al-Walled Sensitive Ionization Chamber . . . 132
P. A. DUFFY

Nuclear Engineering

Valves and Corks to Seal Reactor Shields . . . 134
C. V. MOORE

Departments

ROUNDUP.....*facing* 16
EDITORIAL..... 51
TECHNICAL ADVANCES. 140
APPLIED RADIATION..... 142
BOOKS..... 144
PRODUCTS AND MATERIALS. 168
LETTERS..... 178
NUCLEAR CALENDAR. 179
NEWSMAKERS..... 180

About NUCLEONICS (Continued)

ance of papers for special reports, there is still no experience like nursing a manuscript along from office to office, which of course we did on at least one article in this report.

The final product, by the way, our report on "Radiation Effects," was put together because we felt that the literature nowhere contained a compilation of such data. And this generally is the purpose of our special reports—to bring together "under one roof" widely scattered material of broad interest. Another study that we have in the works is a detailed analysis of what this country—government and industry—has to offer other countries in the way of research reactors and assistance on research reactors.

•

Let it never be said that we don't wring the utmost out of our staff. Even when one of our editors was taking advantage of his Blue Cross benefits last month, he unwittingly contributed copy for this issue. Associate Editor Dan Cooper, hospitalized after leg surgery resulting from showing too much vitality on his vacation, responded to a staff gift of a bottle of vodka by sending the following wire from his hospital bed:

"Shipment of forty percent enriched fuel gratefully acknowledged. Homo-Genus reactor will assuredly go critical now. Am in no position to attempt breeding but may experiment with mild excursions . . . Conversion of morning orange juice to screwdrivers greatly improves local aspect. Many thanks to you all."

We sober, office-ridden staff members were thoroughly amused by the wire and thought we would share it with other reactor specialists.

•

Undoubtedly the inspiration to send Cooper vodka instead of, say, chartreuse, came from his attendance at the weekly lectures on the Russian language given to the staff by our multilingual news editor, John Kenton. Not satisfied with awing us with his almost monthly round-the-clock work stints as his deadline approaches, John feels at home in French, German, Russian, Italian—and English. This helps him deal with our far-flung World News correspondents on an equal footing.

•

We were looking for some unusual twist to make the Trade Fair preview on p. 150 editorially appealing. Try as we could, we always came back to the same conclusion—that the overwhelming number of exhibitors and the diversity of products displayed would serve as sufficient lure to readers. If you disagree, come and tell us about it at the NUCLEONICS booth, number 223, at the Atomic Industrial Forum Trade Fair in Chicago later this month.

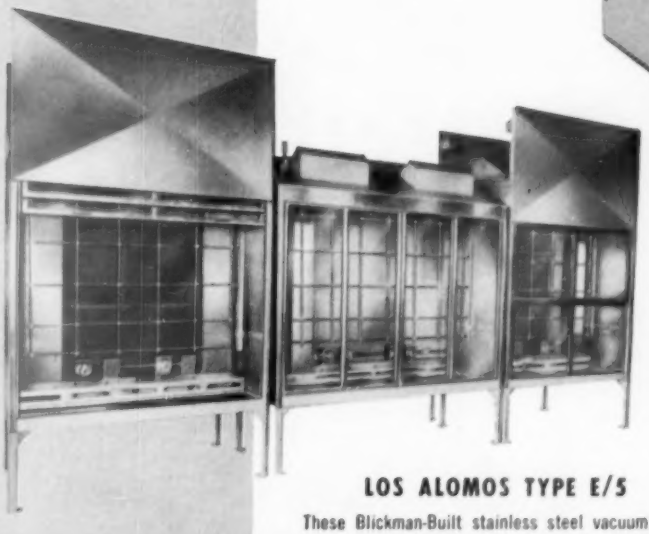
—*The Editors*

Blickman-Built

STAINLESS STEEL

VACUUM RACK ENCLOSURES

FOR HANDLING RADIOISOTOPES AND RADIOACTIVE MATERIAL



LOS ALOMOS TYPE E/5

These Blickman-Built stainless steel vacuum rack enclosures are designed for the safe handling of radioactive materials in research applications. Two types of racks are available.

TYPE E5-1 has a vertically-rising door. A similar door can be provided on the opposite side if operation from two sides is desired.

TYPE E5-2 has sliding doors with can also be provided on the opposite side for two-sided operation. Available in various lengths to meet specific requirements.

CALIFORNIA TYPE E/8

Seamless, crevice-free, round-corner construction assures easy cleaning, facilitates decontamination.

This Blickman-Built hood is designed for the handling of hazardous substances such as radioactive isotopes and other radioactive materials. The air supply to the hood is filtered through expendable type filters located at both ends.

Send for Technical Bulletin ... also folder illustrating **Blickman-Built** Stainless Steel Specialized Laboratory Equipment

See us for information on new Modular Safety Laboratory at the Atomic Industrial Trade Fa[illegible] Navy Pier, Chicago, Ill., Booth #210-211, Sept. 24-28, 1956

EST. 1889

S. BLICKMAN INC.

7909 Gregory Ave. · Weehawken, N. J.

STAINLESS STEEL LABORATORY EQUIPMENT

FUME HOODS · DRY BOXES · ANIMAL CAGES · PROCESS UNITS · PEG BOARDS · SEMI-HOT FUME HOODS · LABORATORY TABLES · DRY WASTE CONTAINERS · LIQUID WASTE CONTAINERS · LABORATORY STOOLS · STAINLESS STEEL SINK UNITS · ENCLOSURES · SHELVING · CABINETS · CASEWORK · TRAYS

General Electric EM* Pumps . . .

Move liquid metals with greater safety and continuity

. . . OPERATE WITHOUT MOVING PARTS, SEALS, OR BEARINGS

General Electric electromagnetic pumps, first designed for radioactive and high-temperature systems, are now used in liquid metal laboratories and industrial processes where minimum leakage and continuous operation are important.

Now designed to pump liquid metals at temperatures up to 1500 degrees F and to move up to 10,000 gallons per minute with accurate control of flow, General Electric EM pumps can be used to move such metals as sodium, sodium potassium, lead, bismuth or mercury.

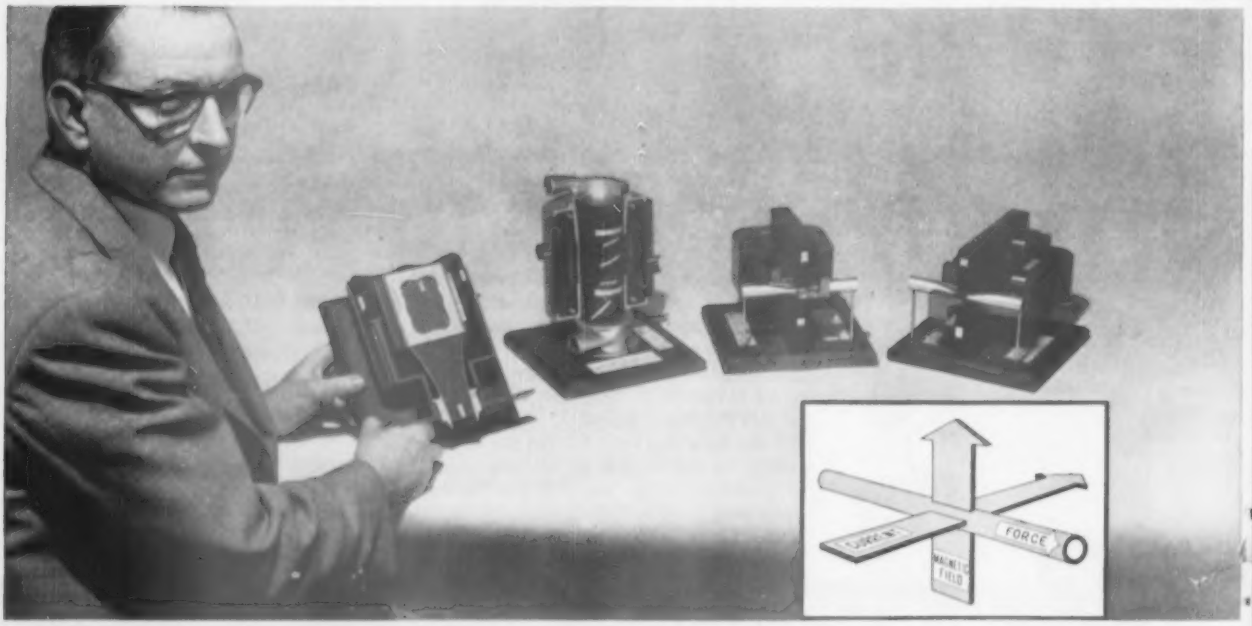
***Electromagnetic**

General Electric offers complete liquid metals pumping systems including EM pumps, magnetic flowmeters, liquid level indicators, pressure transmitters, induction heaters, cold traps, plugging indicators and sodium oxide control stations.

For more information on liquid metals pumping systems and components, contact your nearest G-E Apparatus Sales Office, or Section 193-1, General Electric Company, Schenectady 5, New York. Outside of the U.S. and Canada write to: International General Electric Company, 570 Lexington Avenue, New York City, N. Y.

Progress Is Our Most Important Product

GENERAL ELECTRIC



FOUR GENERAL ELECTRIC EM PUMP MODELS are shown by **J. F. Cage, Manager—Component and Coolant Systems Engineering Operation, Atomic Power Equipment Department, (l. to r.): linear induction, helical flow, d-c, and a-c types. Diagram shows pumps' operating principle: Force is exerted on current-carrying liquid in magnetic field.**

LIQUID METAL LOOP tests sodium potassium (NaK) in a G-E electromagnetic pumping system for use as heat-transfer agent. Loop's a-c EM pump (below) operates at 600 degrees F with capacity of 30 gallons per minute. Magnetic flowmeter (left of pump) measures flow externally, providing greater safety.

GENERAL ELECTRIC

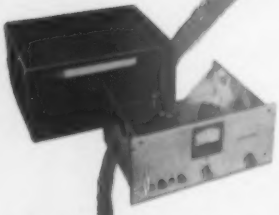
Nuclear INSTRUMENTS FOR

Log N Amplifier

Sigma Amplifier

Weston
Radiation Densitometer Meter

Parallel Circular Plate
Chamber



Log Count Rate Meter

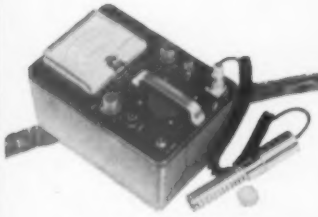
Weston
Health Protection Densitometer

Miniature Log Count Rate Meter

A1 Amplifier

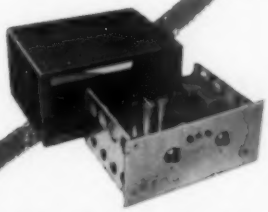
DAYSTROM, inc.

RESEARCH AND POWER REACTORS, PROCESS CONTROL AND RADIATION.



Heath Geiger Counter

Weston
Strip Chart Multiple Point Recorder



Single-Channel Analyzer

Weston
Recording Controller

Compensated Ionization Chamber

- *Composite Safety Amplifier
- *Compensated Ionization Chamber Power Supply
- *Log Count Rate Meter
- *Log N. Amplifier
- *Magnet Amplifier
- *Sigma Amplifier
- *Compensated Ionization Chamber
- Remote Monitron
- Transistorized Reactor Control Instruments
- Recorders
- Single Channel Analyzer
- Period Amplifier
- *Linear Amplifier
- *Linear Preamplifier
- Scalers
- 30 Watt Transistor Magnetic Amplifier
- *Parallel Plate Ionization Chamber
- Custom-built equipment
- Controllers

*Immediate Delivery

DAYSTROM NUCLEAR DIVISION
Elizabeth, N. J.

WESTON ELECTRICAL INSTRUMENT CORP.
Newark, N. J.

Visit us at The Atomic Trade Fair
Booth #247
Sept. 24-28
Navy Pier, Chicago, Illinois

DAYSTROM ELECTRIC CORPORATION—*Poughkeepsie, New York*
DAYSTROM INSTRUMENT DIVISION—*Archbald, Pennsylvania*
DAYSTROM INTERNATIONAL DIVISION—*Newark, New Jersey*
WESTON ELECTRICAL INSTRUMENT CORPORATION—*Newark, New Jersey/Ponce, Puerto Rico*

DAYSTROM NUCLEAR DIVISION—*Elizabeth, New Jersey*
DAYSTROM PACIFIC CORPORATION—*Santa Monica, California*
HEATH COMPANY—*Benton Harbor, Michigan*
DAYSTROM FURNITURE DIVISION—*Olean, New York/Alma, North Carolina*

Recent Shielding Installations

U. S. S. Nautilus

•

U. S. S. Seawolf

•

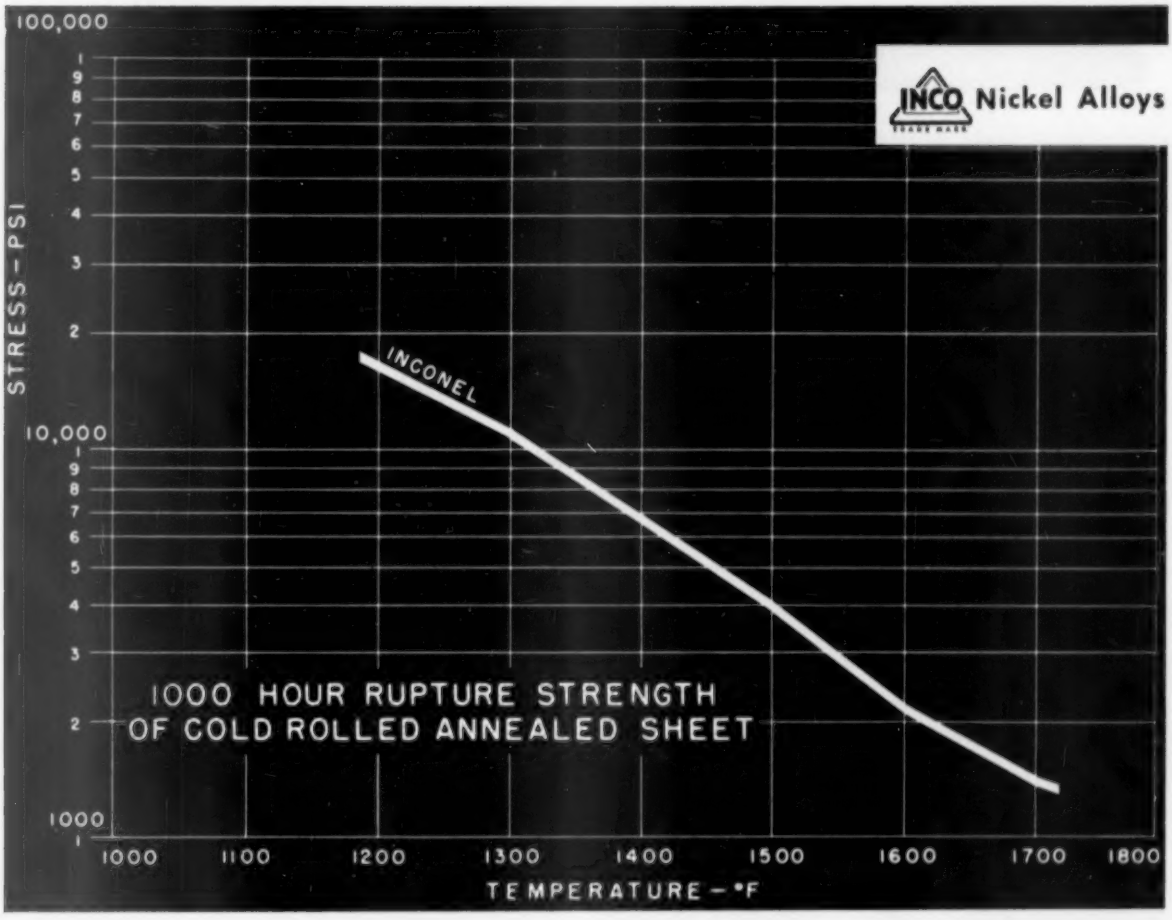
SIR Prototype
West Milton, N. Y.

•

MARK 1 Prototype
Arco, Idaho

and Company

BOSTON 22, MASSACHUSETTS



You can stress this Inco alloy hundreds of hours in great heat

Need metal that resists deformation under continued high stress at high temperatures and in corrosive atmospheres?

You have it in Inconel* nickel-chromium alloy.

Inconel alloy is unique in its high performance characteristics at elevated temperatures. It is widely used in heat-treating, in high-temperature chemical processing, in jet aircraft engines.

In the field of nucleonics . . .

Inconel nickel-chromium alloy is used in uranium metallurgy and other processes where high temperatures are a factor. Here's why:

Inconel alloy is structurally stable. It is not subject to embrittlement on prolonged heating in non-sulfidizing atmospheres.

Inconel alloy is chemically stable. It resists damage by oxidation, carburization and most other forms of high-temperature attack.

Inconel alloy is mechanically stable. It retains useful properties to 2100°F., and over, in some applications, and withstands thermal shock.

Inconel alloy is easy to work . . . easy to form, machine, weld . . . available in all commercial wrought forms.

* * *

For complete information on Inconel (and age-hardenable Inconel "X") alloy, write for Inco's 24-page Technical Bulletin T-7.

*Registered Trademark

The International Nickel Company, Inc.
67 Wall Street New York 5, N. Y.

PHYSICAL CONSTANTS OF INCONEL ALLOY
Non-magnetic

Density lb/cu in	0.307
Specific Gravity	8.51
Melting Point °F	2540-2600
Specific Heat (32-212°F) Btu/lb/°F	0.11
Thermal Expansion Coefficient (32-212°F) 10^6 in/in/°F	6.4
Thermal Conductivity (32-212°F) Btu/sq ft/hr/°F/in	104
Electrical Resistivity (32°F) ohms/cir mil ft	590
Tensile Modulus of Elasticity 10^6 psi	31
Torsional Modulus of Elasticity 10^6 psi	11

MILL FORMS

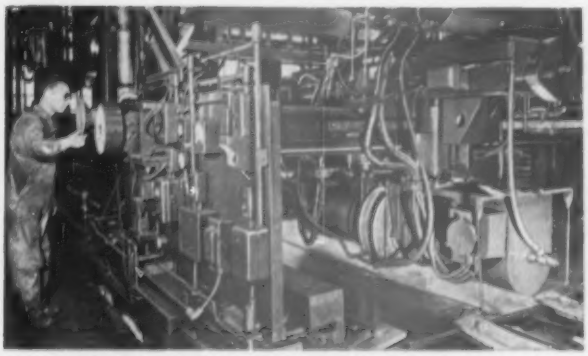
Cold rolled sheet	Cold drawn seamless pipe
Cold rolled strip	Extruded tubing
Hot finished rods & shapes	Hot rolled plate (solid)
Hot rolled angles	Forged billets & shapes
Cold drawn rods & shapes	Hot rolled sheet
Cold drawn seamless tube	Castings
Condenser tube	Cast fittings
	Hot rolled plate (clad steel)
	Wire

Inconel . . . *for long life at high temperatures*

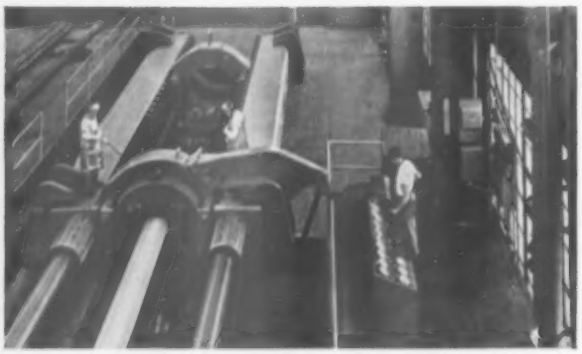
B&W AND ATOMIC ENERGY

Behind B&W Atomic

independent nuclear research • 90 years of



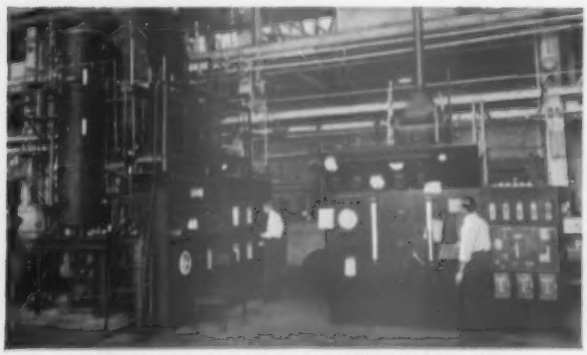
B&W-designed electrical-resistance welding process clads base plate with alloy sheet.



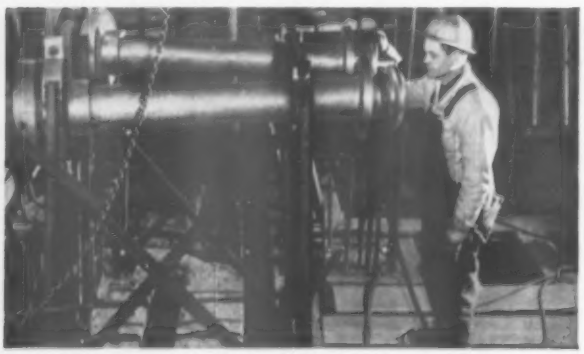
Massive draw bench produces heavy-wall, large-diameter hollow forgings.

8500-ton hydraulic press bends and forms heavy plate, pierces ingots.

Critical Experiments Facility at Lynchburg, Va. for simulation of actual core operation.



B&W's Main Research Center at Alliance, Ohio where continuing program of independent nuclear research is carried on.



Experience, skills and tools developed over 90 years are applied to design, fabrication and erection of nuclear steam generators.

Energy Experience...

steam power experience • specialized facilities

Many of the components in nuclear steam generating systems are remarkably like those in use in modern conventionally-fueled power plants. And in the design and fabrication of reactors and fuel elements, many of the solutions to problems — in metallurgy, metal working techniques, heat transfer and fluid flow, and welding — are being found through extensions of past B&W experience and research.

In this very real sense B&W offers you the benefits of 90 years of experience in design, fabrication, testing and erection . . . the skills and techniques acquired and developed through the creation of thousands of conventional-fuel, high pressure boilers. You get the advantages of direct atomic energy experience accumulated since the days of the Manhattan Project through active participation in many AEC-sponsored projects . . . the practical results of B&W's own continuing program of independent nuclear research and development.

These, together with specialized facilities, form the unique background B&W brings to single components, or the design, fabrication, testing and erection of complete nuclear steam generating systems, from fuel elements to turbine throttle.

The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

BABCOCK & WILCOX

ATOMIC ENERGY DIVISION

AE-34

First "service" station for submarine reactors ...transition shield of LEAD brick

Here's something new in the swiftly advancing technology of atomic power . . . a chamber devised for recharging reactors of submarines . . . and maybe, someday, reactors of ships, planes, locomotives and stationary power plants. Here, shielded by lead, men can service equipment safely.

The specially designed bricks were produced by National Lead. They stack and fit perfectly, in a circle . . . without mortar. Inner surfaces are contoured to the chamber arc. Interfaces are also curved . . . to mate and mesh in a structurally sound configuration. Nowhere does a crack offer a straight-line path for radiation.

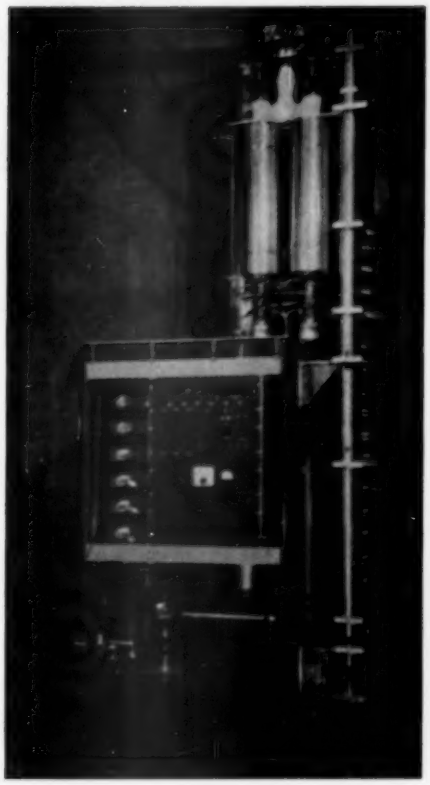
Maybe you need lead brick . . . extruded, curved "Protecto" brick . . . or conventional, flat-sided extruded brick. Maybe you want lead in some other standard form . . . sheet, slab or sleeving, for instance. Maybe you want some specially built shape.

You can get lead shielding the way you want it from National Lead. Just call the nearest branch.

National Lead Shielding

NATIONAL LEAD COMPANY, New York 6; Atlanta; Baltimore 3; Buffalo (Depew P. O.); Chicago 80; Cincinnati 3; Cleveland 13; Dallas 2; Philadelphia 25; Pittsburgh 12; St. Louis 1; Boston 6 (National Lead Co. of Mass.); Los Angeles 23 (Morris P. Kirk & Son, Inc.); Toronto, Canada (Canada Metal Company, Ltd.).

THE FIRST COMMERCIAL LINEAR ACCELERATOR



The accelerator shown in the photograph will be installed at the W. F. and John Barnes Company, Rockford, Illinois, where it will be used for pilot plant studies of radiation processing. During the last several months the reliability of this accelerator has been proven in the performance of irradiation services for customers from all over the world.

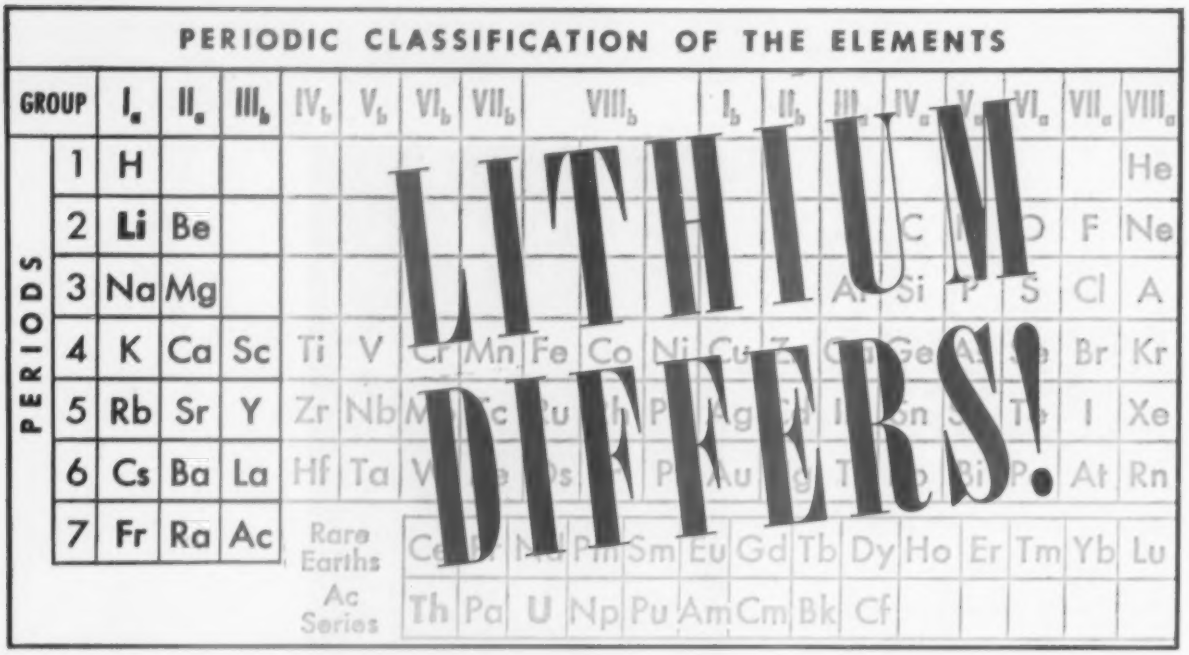
IRRADIATION SERVICE Another ARCO linear accelerator is being installed in ARCO's new plant at Walnut Creek, California where it will be used exclusively for contract irradiation work.

MARK I ACCELERATOR SERIES

- Available with electron beam energies from 2 to 12 million volts
- Electron beam power from 1 to 10 kilowatts
- X-ray field intensities up to 1,200,000 rad per hour at 1 meter
- Fast neutron production up to 2×10^{12} per second by gamma-n processes
- Thermal neutron fluxes up to 10^{9} per second per cm^2

Other linear accelerators are available on special order with energies ranging to 50 million volts, beam powers to 60 kilowatts, x-ray field intensities to 10,000,000 rad per hour at 1 meter, fast neutron production to 10^{14} neutrons per second. Write for details.

ARCO
APPLIED RADIATION CORPORATION
WALNUT CREEK, CALIFORNIA



Lithium, by reason of its atomic configuration and general characteristics, is rightfully included as the first member of Group I in the Periodic Table. A detailed study of the properties and reactions of both the elements and their compounds, however, shows that Lithium often resembles the metals of Groups II and III more closely than Group I. Following are some characteristic differences:

Lithium differs in organic chemistry . . .
because its organolithium compounds form a unique class with stability, solubility and activity characteristics intermediate between those of the Group I and Group II organometallic compounds.

Lithium also differs from the other alkali metals in that it serves as a unique catalyst for the polymerization of diolefins to materials of definite and predictable structure. It directs, for example, the polymerization of isoprene predominantly to 1,4 addition structures.

Again, recent investigations have indicated an interesting potential as a direct reducing agent in solvents such as ammonia, low molecular weight amines, and ethylenediamine.

Lithium differs in metallurgy...
inasmuch as the affinity of Lithium for oxygen, for example, is being utilized to reduce porosity in copper and copper alloy castings. Recent research has revealed that Lithium will produce brazing alloys with self-fluxing properties and increase the wetting ability of these alloys.

Lithium differs in inorganic chemistry . . .
the usefulness of Lithium Hydride and Lithium Aluminum Hydride in the preparation of other hydrides having already been widely demonstrated. Recent studies indicate that other complex hydrides prepared in a similar manner may prove to be interesting tools for research. The low dissociation pressure of Lithium Hydride at its melting point, to cite a specific example, is unique among all hydrides. LiH also has some slight solubility in polar organic compounds which is again unique among alkali metals.

Lithium differs in heat transfer . . .
based on its physical properties it has no equal as a liquid metal coolant. Due to corrosion caused at elevated temperatures by impurities in commercially available Lithium and Lithium Metal, Lithium has thus far found only experimental use.

Why don't *you* take a long look at Lithium? Its uniquely valuable differences in so many diverse fields may prove of great interest—and profit—to *you*. Write our PR&D department giving us details of the application you have in mind. Experimental quantities of Lithium Compounds are available on request.

. . . trends ahead in industrial applications for lithium

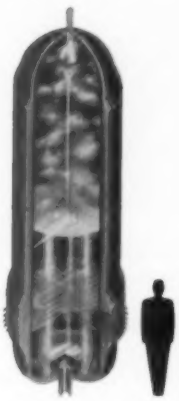
LITHIUM CORPORATION OF AMERICA, INC.
2595 RAND TOWER
MINNEAPOLIS 2, MINN.

MINES: Keystone, Custer, Hill City, South Dakota • Bessemer City, North Carolina • Cat Lake, Manitoba • Amos Area, Quebec • BRANCH SALES OFFICES: New York Pittsburgh • Chicago • CHEMICAL PLANTS: St. Louis Park, Minnesota • Bessemer City, North Carolina • RESEARCH LABORATORY: St. Louis Park, Minnesota

Steam Generators by Foster Wheeler are

FIRST MAJOR COMPONENTS TO ARRIVE AT SHIPPINGPORT

World's First Full-Scale Atomic Power Plant will be served by two FW steam generators and a large FW pressurizer



Cutaway drawing of Foster Wheeler electrically heated pressurizer for Shippingport Power Plant

Scheduled for completion in 1957, Duquesne Light Company's Shippingport plant is making rapid progress in construction, as shown by the photograph above. The two FW steam generators for this atomic power plant were shipped right on schedule, and were the first major components to arrive at Shippingport. The steam generators will convert heat from the nuclear reactor into steam for operating the turbo-generator. The nuclear reactor is being built by Westinghouse Electric Corporation for the U. S. Atomic Energy Commission.

Also to be supplied by Foster Wheeler is the 18-ft high, 300 cu ft pressurizer shown in section at left. Used to control coolant loop pressure, it is designed for 2500 psig at 675 F. There are 342 electric immersion heaters to supply energy for initial raising of the coolant system, as well as to control pressure during operation.

Foster Wheeler's nuclear know-how—in the design and construction of complete reactor systems or individual components—is available now, to assist in the planning of tomorrow's atomic power plants. For further information, write to *Foster Wheeler Corporation, 165 Broadway, New York 6, New York.*

FOSTER WHEELER

NEW YORK • LONDON • PARIS • ST. CATHARINES, ONT.

NDA_ SPECIALISTS IN HIGH PERFORMANCE REACTORS

the work of converting today's early nuclear reactors into refined engines for electric power generation, propulsion, industrial processing, and research is one of the most challenging engineering tasks of our time — it is the task to which *NDA* devotes its major energies.

NDA participates in reactor development in three ways:

- **it seeks solutions to broad fundamental and applied problems applicable to all reactors — this includes studies in shielding, reactor core design and analysis, heat transfer, fuel element improvement, analysis of nuclear cross sections, and organization of technical information.**
- **it carries out specific reactor design and development projects, including reactors for power, propulsion, industrial processing and research.**
- **it fabricates nuclear fuel elements, reactor cores and other reactor components.**

facilities and equipment recently placed in service by *NDA* include:

- **reactor critical facility.**
- **hot laboratory.**
- **westchester county computing center, with a datatron as the principal computing machine.**
- **rolling mill.**
- **new high temperature experimental apparatus.**

development machine shop

rolling mill

fission product chemistry

for information concerning employment at NDA write

see our exhibit at booth 342, 1956 atomic trade fair

NDA_ NUCLEAR DEVELOPMENT CORPORATION OF AMERICA

5 NEW STREET: WHITE PLAINS, N. Y. · TEL. WH 8-5800

ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

Atomic Attachés

As a next step in what is described as "putting teeth into" the Atoms-for-Peace program, AEC will send top-level people abroad to serve in perhaps a dozen major capitals as attachés in the nuclear energy field. Amasa Bishop, chief of the controlled thermonuclear project, will go to Paris as bellwether in the program. Britain has had a nuclear science attaché, J. A. V. Willis, in Washington for some time, as have Belgium and some others.

•

Pyrophoricity: New Assault

A new crash program to crack the mystery of spontaneous ignition or explosion of zirconium has been ordered by AEC. It will be carried out under contract by a team headed by Irving Hartmann of the Bureau of Mines at the BuMines lab at Bruceton, Pa., outside Pittsburgh. This "quick-and-dirty" study on pyrophoricity [literally, *fire-bearing*] will include experiments to store Zr in various forms in various ways for various periods and then running explosion tests to see which samples tend to activate. Short-range goal is to establish recommended methods for safe storage and handling of currently-existent Zr powders and scrap. AEC hopes to have answers by the end of the year. This study is in addition to the long-range, more basic investigation going on at Argonne (NU, Aug. '56, p. R3) primarily on U, Pu, but including also Th, Zr, Ti. AEC has been increasingly concerned over mysterious fires and explosions of Zr and other nuclear metals, last month sent out a 34-page accident-prevention bulletin summarizing known information. Richard B. Smith, AEC's deputy chief of safety and fire prevention, told NUCLEONICS the three most-suspected villains are stress, contaminants, and exposure to moisture under quiescent conditions. "It looks at the moment as if the causative factors of these unusual incidents are intimately connected with the corrosive effects on metals by water," he says. Knowledge obtained to fight accidents may also, he hopes, provide new insights into basic corrosion mechanisms.

•

Chugach Okayed

The 10-Mw power reactor proposed by Chugach Electric Assn. of Anchorage, Alaska, and Nuclear Development Corp. of America became the third of the seven proposals in the second round demonstration program to obtain AEC approval "as a basis for contract negotiations." Wolverine and Elk River had previously been approved (NU, May '56, p. 18); Piqua, Ohio; Holyoke, Mass., Orlando, Fla., and Florida University remain under consideration by AEC. For its client, Chugach, NDA has suggested building the first reactor combining the best moderator, heavy water, with the best coolant, liquid sodium; NDA feels it is able to lick the problem of preventing contact—and the resulting violent reaction—between the two. Slightly-enriched uranium will fuel the heterogeneous tank-type unit. Over-all plant cost including development will be about $20-million. AEC is being asked for $18,325,000 maximum aid, including $2,225,000 for initial design work and $5.5-million for the reactor itself, to which it would retain title. Chugach will provide site (adjoining a conventional plant in a broad, dry river bed adjacent to the city of Anchorage), reactor housing and the turbogenerator end of the plant, assuming $1,850,000 in capital costs.

NDA says current from the plant will cost about 22 mills/kwh including development costs, about 12 mills to Chugach allowing for AEC aid. The latter figure is about the present cost of hydro power in the area; thermal plants run at about 17 mills at Anchorage, up to 27 in the interior. AEC said this factor—that in Alaska "nuclear power could become economically competitive sooner than in lower-cost areas"—helped it decide; also that the low-enrichment fuel would make the design "desirable for foreign use." The project has been divided into three phases: initial design and development, detailed design and final develop-

ment, construction and experimental operation. At the end of the first two, AEC and the two companies will determine if results warrant continuation of the project. Plans call for completion before 1962.

■

A-Planks and A-Platforms

Whatever else the late Gore bill may or may not have achieved, it endowed the subject of atomic energy with political glamor. The Democratic platform contains a combative plank promising that under the Democrats, the U. S. would lead in bringing the blessings of the peaceful uses of nuclear energy to mankind. It charges the Eisenhower Administration with having "promptly reversed the field and plunged the previously independent and nonpartisan AEC into partisan politics . . . The Republican Administration has followed the same pattern in the field of atomic energy that it has pursued in its treatment of other natural resources—lofty words, little action, but steady service to selfish interests. While the AEC and the special private interests consult and confer, the U. S. is lagging instead of leading in the world race for nuclear power, international prestige, and world markets . . . But the fight to bring nuclear power to the people has only begun . . ." In a six-point program, the Democrats promise to "restore nonpartisan administration of the vital atomic energy program and to expand and accelerate nuclear development by vigorous action"; to accelerate the domestic civilian atomic power program "by the construction of a variety of demonstration prototype reactors"; to give "reality, life and meaning to the atoms for peace program: we will substitute deeds for words." The last three points promise increases in production of fissionable materials, a "comprehensive survey of radiation hazards . . . to protect existing and future generations," and a "balanced and flexible" weapons stockpile.

The Republican platform has less to say; it replies, in a somewhat defensive tone, pledging the party to "continuous, vigorous development of atomic energy." It credits the Eisenhower Administration with breaking the "stalemate" of government monopoly and inaugurating a "strong program for developing the peaceful atom," recites its achievements in this field, and promises to "continue this imaginative, world-embracing program."

■

U. S. Set Back in Brazil

Ultra-nationalists, militarists, and communists in Brazil—diverse groups with some common aims—won their long anti-American campaign to halt thorium exports to the U. S. They also obtained from the Kubitschek government denunciation of the Aug. 3, 1955, agreement for joint U. S.-Brazilian uranium prospecting in Brazil. U. S. purchases of Th have been small—they were to have totaled about 300 tons of oxides this year; but much larger imports had been provided for (NU, Dec. '55, p. 16). Brazil was careful not to abrogate another pact, however: the atoms-for-peace bilateral under which the U. S. will contribute $350,000 toward the cost of a B&W 5-Mw swimming pool for São Paolo University (*see p. R11*), lend technical aid and 6 kg 20%-enriched uranium for it.

●

More Be for AEC

Brush Beryllium Co. and the Beryllium Corp. will share equally a five-year, 1-million-lb Be buying program by AEC, double what AEC asked in January (NU, Jan. '56, p. 16). Each firm will build a new plant, Brush at Elmore, O., Beryllium Corp. at Reading, Pa. Average cost will be $47/lb. AEC's Be needs were met till now from a U. S.-owned, Brush-operated plant at Luckey, O.

●

Waste Disposal Plant Design

Blaw-Knox's chemical plants division is working on design of a full-scale waste disposal plant along lines developed on a laboratory scale at Brookhaven (NU, Dec. '54, p. 14; Dec. '55, p. 27). The process involves reduction of fission products by separation and concentration, then adsorbing and fixing them on montmorillonite clay. Blaw-Knox's engineering study includes design of all nonstandard critical hardware. Job is to be completed by year's end; cost has not been determined.

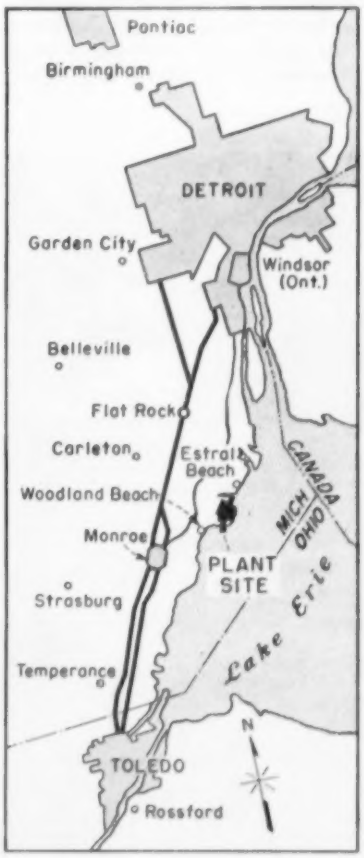
Detroit Breeder Syndicate Proceeds with Building Plans Despite Safety Row; Says Design Problems Being Solved

While questions regarding the safety of Detroit's 100-Mw fast-breeder reactor power station swirled furiously in political circles, the Power Reactor Development Company—builders of the plant—went resolutely ahead last month with a scheduled inauguration ceremony at which the station was dedicated to the memory of Enrico Fermi.

Before a gathering of 450, one year to the day after the opening session of the Geneva Atoms-for-Peace conference, a large sign was unveiled identifying the 915 acres of swampland on the shores of Lake Erie at Lagoona Beach, Frenchtown Township, Monroe County, Mich., as the site of the $54.5-million Enrico Fermi Atomic Power Plant. About 15 of the 915 acres are being filled in to a level five feet above the highest recorded level of Lake Erie. Here PRDC—a Detroit Edison-spearheaded syndicate of 8 manufacturing firms and 18 utilities from Florida to Wisconsin—plans to put up the nation's first privately-sponsored breeder reactor, and to sell steam from it to Detroit Edison, which is building the adjoining turbogenerator end of the plant.

At the ceremony, representatives of the Common Council of Detroit (30 miles to the north); of Monroe, Mich. (pop. 21,000, 8 miles to the south); and of Frenchtown Township welcomed the plant and said they were pleased and proud that it would be located there. The main speaker, AEC chairman Lewis L. Strauss, brought a letter of congratulation from President Eisenhower. Strauss also remarked that "some rather violently-voiced opposition in Washington" to the granting of a conditional construction permit for the plant "was not entirely unanticipated" by AEC. This opposition, he said, is part of an "attack being directed against the free enterprise development of nuclear power in this country"—an attack which, "if successful, would weaken if not eliminate free competition and return atomic energy to its former condition of a government monopoly." The question of safety, he said, "has been raised by some who oppose this enterprise; I want to say to you that when this plant comes into operation, it will only be in compliance with the Commission's rigid health and safety requirements."

The question had been raised just prior to the adjournment of Congress by two Democratic members of the Joint Committee on Atomic Energy, Sen. Clinton P. Anderson, chairman, and Chet Holifield; by AEC Commissioner Thomas E. Murray; and by Michigan's Gov. G. Mennen Williams. They based their objections on an unpublished report by AEC's Advisory Committee on Reactor Safeguards that held that "there is insufficient information available at this time to give assurance that the PRDC reactor can be operated at this site without public hazard" unless a small-scale prototype plant is built first (NU, Aug. '56, p. R2). ACRS—which makes no recommendation, either for or against issuance of a construction permit—went on to declare that "it appears doubtful that sufficient experimental information will be available in time to give assurance of safe operation of this reactor unless the present fast-reactor program of the AEC is amplified and accelerated," and that "it is impossible to say whether or not an accelerated program would give sufficient information to permit safe operation of this reactor at the Lagoona Beach site on the time schedule presently proposed."



The United Auto Workers and other big unions filed petitions with AEC seeking to block construction of the plant. Walter Reuther, UAW head and vice-president of the AFL-CIO issued a statement scoring AEC for "betraying public confidence," and was reported trying to get union labor to walk off the job.

Politically speaking, the fat was in the fire when on Aug. 3—only five days prior to the scheduled inauguration ceremony—Strauss announced the granting of a "conditional" construction permit for the reactor. Anderson said issuance of this permit "sets a dangerous pattern in the early stages of AEC regulative and quasi-judicial activity" because AEC acted "as a result of 'star chamber' proceedings" overriding the safeguards committee report; because Governor Williams "has apparently been precluded from being heard or participating in any decision to build this reactor"; because the method of issuance of the permit "raises serious questions as to whether AEC has violated established legal principles by the confusion of its development and promotion functions with its regulative and quasi-judicial responsibilities"; and because "from a practical standpoint, AEC might feel obligated to go through with a bad deal with respect to public safety because they will have permitted the expenditure of huge sums under the construction permit." Anderson also took note of Strauss' testimony on June 28 before the House Appropriations Committee "flatly stating" that he would attend the Aug. 8 ceremony: "the issuance of the permit on Aug. 3 thus fits into this arrangement perfectly." Anderson warned that he "expected to ascertain the full facts involved in this precipitate action."

Rep. Holifield likewise lashed out at Strauss: " . . . In overruling the grave warnings of his own Advisory Committee on Reactor Safeguards, [Strauss] has, in my opinion, proceeded in a reckless and arrogant manner. . . . The report of the Committee has been suppressed. I

believe it has been suppressed deliberately. . . . I will introduce a legislative proposal in the next session of Congress which will separate the promotional activities of the AEC from its quasi-judicial functions. The people of the U. S. have a right to objective judicial review of safety matters divorced from any promotional objectives which may dominate AEC thinking." Holifield also raised the question of the bearing of the EBR-1 meltdown (NU, May '56, p. 17; June, p. 35) to the safety of the PRDC reactor. Anderson and Holifield telegraphed Gov. Williams to halt construction of the project, and asked President Eisenhower to instruct AEC to withdraw the permit.

However this position was not borne out by a special atomic energy study committee Williams had asked to look into the matter. This committee concluded that "the recent charges and adverse publicity were apparently based on incomplete and inadequate information and a lack of understanding and knowledge necessary equitably to evaluate a project of this nature."

"Criticism of the project at this time," the report continues, "is premature since in any new project of this magnitude and type all of the design data is never available previous to the genesis of construction. . . . PRDC has demonstrated to the satisfaction of this committee that they have continuously cooperated, consulted with and kept all federal and state agencies informed on the progress of the project.

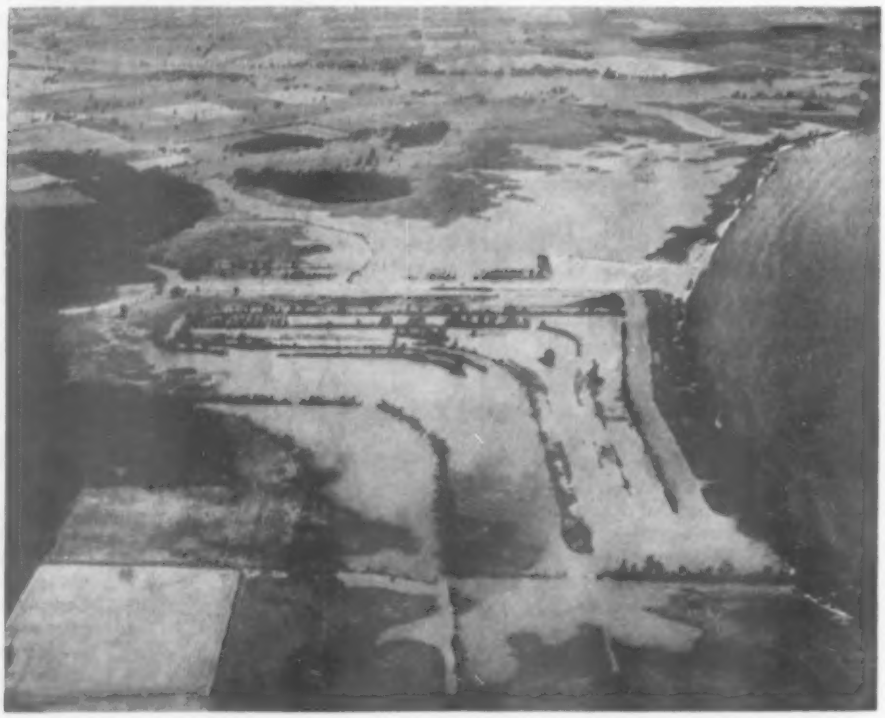
"Finally," the committee went on, "we observe that our examination has revealed nothing which would label the project as unsafe inasmuch as the Advisory Committee only said in effect that there was insufficient information and data available to them *at this time* in order to pass on the adequacy of safeguards. We believe the omission of the words *at this time* in any publicity given to this matter has led to the inference that the PRDC proposal is unsafe."

AEC's Conditions

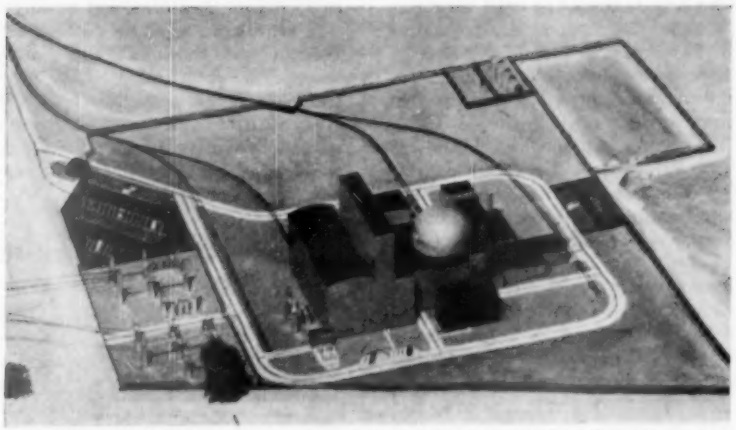
There were observers who, while agreeing fully that criticism was premature at this stage with much development work obviously remaining to be done, nevertheless felt that AEC had left itself open in issuing a conditional permit. They recalled that earlier, when the Commission was being pressed by JCAE for action on the Con Edison and Commonwealth permit applications, AEC took the position that it could not act until all the requirements of the safeguards committee had been met. Actually, a construction permit by its very nature is conditional, with issuance of an operating license contingent on the completed plant's meeting completely the rigorous safety requirements. The permits granted Con Edison and Commonwealth earlier contain a statement that the applicant "has submitted sufficient information to provide reasonable assurance that (the reactor) can be constructed and operated at the proposed location without undue risk to the health and safety of the public."

However, AEC emphasized much more strongly the conditional nature of the PRDC permit. To some observers, it seemed as though AEC was essentially saying to PRDC: We have major doubts that you can comply with our safety requirements when you say you can, but as long as you understand that you've got to meet the requirements before you get your operating permit, we'll give you a construction permit because it's your money you're risking on the chance that you'll be able to follow your schedule.

In a covering letter accompanying the permit, AEC told PRDC: "As stated in the construction permit the Commission believes that the safety problems associated with the reactor will prove to be of a kind which can be resolved within a reasonable time. . . . However, the Commission wants it to be



AERIAL VIEW looking north shows 15-acre site being filled in—the white patch at right center—and 900 acres of exclusion area, mostly swampland, surrounding it. Crossing picture horizontally is new access road to site. Parallel to it near top of picture is Swan Creek, northern limit of exclusion area. Farms at upper and lower left are outside Detroit Edison territory. Plant will be built on right side of filled area, nearest Lake Erie. Distance is 8 mi to Monroe, 10 mi to Flat Rock, 26 mi to downtown Toledo, 28 mi to Cadillac Square in Detroit



FAST BREEDER MODEL shows how plant will look when completed. Dome is reactor vapor container; to left is large turbine-generator building; below, office building; to right, fuel handling and disassembly facilities. Top right are storage tanks and a holdup basin for waste water. Herringbone lines on either side are auto parking spaces. Lake Erie shore runs parallel to, just below, bottom of picture

clearly understood that in issuing this construction permit the emphasis is on the fact that it is a conditional one and that the Commission can make no commitment to convert the permit to a license until it is satisfied on all safety matters."

The construction permit itself defined "identified areas of uncertainty regarding the hazards potential of fast neutron breeder reactors that must be investigated and resolved," and added that other areas of uncertainty may arise. The permit described those now known as follows:

"(a) Whether there exists in the PRDC reactor a positive component of the temperature coefficient similar to that exhibited in the Commission's experimental breeder reactor (EBR-1). The source of the positive component of the temperature coefficient exhibited by EBR-1 (presently believed to be caused by dimensional distortion of the core structure) must be identified and its effect, if any, in the PRDC reactor must be eliminated.

"(b) Whether there is a credible condition of meltdown and reassembly of the fuel of the PRDC reactor which could result in an explosion that would breach the gas-tight building surrounding the reactor. Further investigations must be carried out to establish that a credible condition of meltdown with consequent U^{235} accumulation of critical dimensions cannot result in such an explosion."

The permit goes on to state AEC's belief on the basis of information now available that these safety problems will prove to be of a kind that can be satisfactorily resolved within a reasonable time. However, the permit adds, "there is some doubt whether they can be resolved in time to meet the schedule proposed by PRDC in its application and it may turn out that further investigations beyond the program of investigation outlined by PRDC in its application will be needed."

Almost entirely overlooked in the hue and cry over safety problems was another AEC reservation that some people fear may be at least as serious: financing. The permit states that although PRDC has submitted evidence of bank commitments for a loan of $15-million and has described plans for obtaining additional financing from member companies, "the evidence submitted to date does not justify a finding with respect to the financial qualifications of PRDC." Accordingly, it provides that unless PRDC can fill this gap within 12 months, the permit is to expire.

Detroit's Answers

The Detroit design and construction syndicates are confident they can lick the technical problems remaining, and they have gambled $2.4-million already spent for plant hardware (NU, April '56, p. 22), over and above the $8-million for research and development to establish the basic plant design. NUCLEONICS asked the designers of the Enrico Fermi reactor what is being done to meet AEC reservations on the two areas of technical uncertainty defined in the permit. Their replies are as follows.

"(a) In EBR-1, the fuel rods are supported only at their ends. Therefore, the radial temperature gradient in the reactor causes the rods to bow, with the rod centers nearer the reactor centerline than are the ends. If the power increases, the temperature gradient also increases and the rods bow more. The inward bowing of the fuel rods tends to increase the reactivity of the core, thus causing further power increase and further bowing. This positive power coefficient is only noticed when the power is increasing rather rapidly and heat does not have time to be transferred to the NaK coolant where increased temperature would decrease density and therefore reduce reactivity.

"The Detroit designers are getting around this bowing in several ways. Fuel pins are much thinner than in EBR-1, reducing the forces needed to restrain bowing; and they are packed so tightly that they cannot bow. The assembly structure in which the pins are located is designed so that sufficient cooling is provided along its length to prevent thermal expansion and subsequent bowing of the whole assembly.

"(b) The designers contend first that the reactor is designed to prevent meltdown. No conceivable way of draining the core of sodium has been found, and with sodium in the system the reactivity available is so low as to prevent power excursions large enough to cause melting in any but very small local areas, if at all. Tests are planned to study the behavior of melting fuel pins with and without sodium present. A region at the bottom of the reactor is provided where all the fuel could accumulate as a molten pool without becoming critical."

Researches are continuing in these two fields so that ironclad proof can be submitted to AEC in support of these contentions.

The conditions attached to the construction permit are a routine matter, Walker L. Cisler, president of PRDC and of Detroit Edison, told NUCLEONICS; what is still uncertain we will go ahead and test, he said.

"This will be a safe reactor, or it won't go into operation as far as we are concerned," he declared. "We've got too great a responsibility . . . it's inconceivable that we should do anything not in recognition of our responsibility to the public."

Progress in Italy Reported On Varied Nuclear Projects

The log-jam in the Italian nuclear effort caused by the struggle for supremacy between government and private industry may be easing, in spite of the resignation of Francesco Giordani, president of CNRN (Comitato Nazionale per Ricerche Nucleari—National Committee for Nuclear Research). Here are some recent developments reported by NUCLEONICS' Rome correspondent:

Fiat and Montecatini, two of the greatest private industrial empires in the country, have signed an agreement for fuller collaboration in the nucleonics field. Under it, a new company has been created: SORIN (Società Ricerche Impianti Nucleari —Nuclear Powerplant Research Co.) with initial capitalization of $160,000, which may be raised to $1.6-million. Headquarters are in Milan. Purpose of the company is to promote development of equipment and to obtain plants for the industrial utilization of nuclear power. It plans to set up both research and study centers and complete nuclear powerplants. According to reports in the Italian press, the company's first step will be to set up a 3-Mw reactor which, it is stated, President Eisenhower is donating to honor the memory of Enrico Fermi; it is to be used for research and radioisotope production.

The manager of SELNI (Società Elettronucleare Italiana—Italian Electro-Nuclear Company), a syndicate set up by Italy's leading power companies, has just returned from a month-long tour of USAEC research centers and talks with American industrial and utility groups.

Italy's CP-5 research reactor, to be built by ACF Industries (NU, April '56, p. 17) has had its design beefed up to 10-Mw. The increased neutron flux will permit not only experimental work and production of small quantities of plutonium, but also use of the reactor for materials testing on a small scale. The CP-5 is to be erected in the neighborhood of Ispra (Varese commune), on the eastern shore of Lake Maggiore, where a nuclear powerplant also is planned. A metal works built for CNRN will be transferred there also.

Italy's 1-Bev synchrotron, which is being built at Frascati near Rome, will go into operation next year. Work on the $1.6-million facility—to be the most powerful in Europe—is well advanced, and all components are to be finished by next August. Italian firms are fabricating the electromagnet, the magnet power supply, the high-voltage plant and the injector, as well as radio-frequency equipment and measuring and control instruments and circuits.

A course in nuclear physics for industry will be given for the first time at Rome University in 1956–57. Thirty students will attend.

A number of advanced courses are available in Milan. About 100 engineers a year take three courses given at the laboratories of CISE (Centro Informazioni, Studi ed Esperienze—Center for [Nuclear] Information, Studies and Experiments) and the Institute of Experimental Physics. Two experimental courses for nuclear engineers are offered at the Politecnico—the engineering faculty of Milan University: one is a postgraduate course in applied physics, the other is in practical use of isotopes. Both last six months; enrollment has been expanded to 35, but applications are much more numerous. Companies send staff members and pay their tuition.

At the first Rome Nuclear Power Congress in July, the question of governmental vs. industrial control of atomic energy was thoroughly discussed, and the conclusion reached that the most desirable course is to harmonize the two following the U. S. pattern of permitting development by private enterprise subject to government control. The total number of Italians with special training in nuclear energy was estimated at 1,000, including those in government, private industry, and universities. Italian uranium production was seen as "not brilliant": of the estimated world output of metallic uranium in 1950–55 of 15-million kg, Italy contributed 130 kg—and this includes 25 kg of nitrate obtained in 1943–46 from a mine near Cuneo. However, uranium-bearing ores are known to exist in Piedmont, Calabria, and Sardinia, and some coastal sands contain zirconium and thorium. Until now, systematic prospecting has been fragmentary (expenditure for mineral research work 1946–55 has not exceeded $500,000). One cause is the lack of a law protecting private prospecting enterprise.

OUTSIDE of Trombay swimming pool for Asia's first reactor is seen here (details p. R11)

Nuclear Powerplant to Rise Amid Chateaux of Loire

On the south bank of the Loire between its confluence with the Indre and with the Vienne is a flat 200-acre tract chosen to be the site of France's first commercial nuclear plant. Lying as it does in the heart of the chateau country it may seem an incongruous site: barely 5 miles SE are the storied ruins of the castle of Chinon, and in the immediate vicinity are other major historical monuments at Saumur, Fontevrault, Ussé, and Azay-le-Rideau. But rich as it is in historical lore, the region is poor in energy; so Electricité de France has chosen it for its first nuclear central station. Preparatory site work is under way (NU, Aug, '56, p. R11), and actual construction is to begin within a month. The national electric utility will build and operate the plant; the Commissariat à Energie Atomique will furnish the fuel and moderator.

The EDF-1 reactor will be much the same as the G-2 at Marcoule (NU, April, '56, p. 22). Loading will be 100–150 tons of natural uranium formed into 1,000 rods; 1,000 tons of graphite will serve as moderator. Fuel rods will be spaced 20–25 cm apart in vertical channels. Heat output of 150 Mw will be cooled by CO_2 at 360 psi—66% higher than the CO_2 pressure at Marcoule. Net electric output will be 60 Mw. Most of the major decisions regarding the reactor have been made, and final refinements are being firmed up now. The reactor is slated to begin operation in 1959. In January Electricité de France will begin studies on EDF-2, to be built on the same site. France's over-all nuclear power plan provides that installed capacity should at least double every three years.

AEC to Spend $3.4 Million More for Nuclear Education

On the eve of its Gatlinburg nuclear education conference (NU, Aug. '56, p. R12), AEC announced

a new aid program that in fiscal '57 will distribute $3-million for nuclear equipment, research and training aids for universities, and $400,000 to lend nuclear materials free or sell them at 20% off list. This is in addition to the fellowship aid program, up from $216,000 in fiscal '56 to $380,000 next year.

AEC also convoked representatives of 75 universities to discuss its plans to double the output of the Oak Ridge School of Reactor Technology (ORSORT). Enrollment has already been increased this year from 90 to a maximum 120; it is hoped to increase this to 240 by giving the first, preparatory half of the course outside ORSORT at other campuses, and enrolling two classes each year.

Meanwhile, MIT has received a whopping $500,000 grant from the National Science Foundation to help build its research and training reactor. The Ford Foundation has given $400,000 to CERN, the European Organization for Nuclear Research.

Hinshaw of JCAE Dead; Aided Propulsion Research

Carl Hinshaw, Republican Congressman from Pasadena—Glendale, Calif., since 1938, prominent member of the Joint Committee on Atomic Energy, died Aug. 5 after a brief illness. He was 62. A civil engineer and leading Congressional authority on aviation, he had been an enthusiastic spurrer of nuclear propulsion development, particularly for aircraft; he headed JCAE's research and development subcommittee in the 83d Congress.

Industry Use of Isotopes Up 500%, Forum Reports

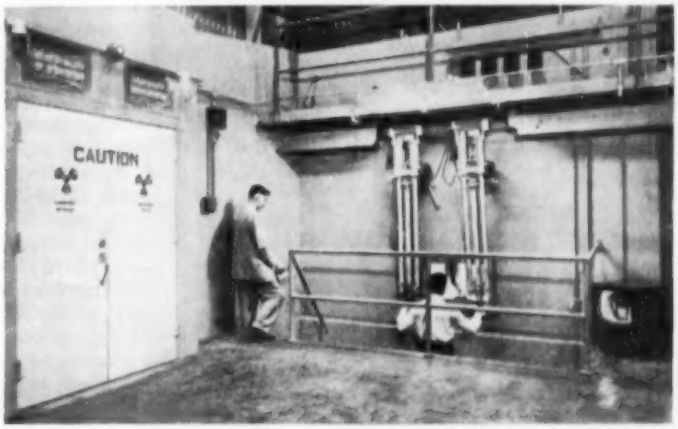
By February of this year, there were 1,020 industrial users of isotopes with 1,347 installations in the U. S.—a 500% increase over five years ago, according to a comprehensive report on ten years of industrial utilization of radioisotopes just completed by the Atomic Industrial Forum. Starting with the birth of the AEC isotope-distribution program in August 1946 (NU, Aug. '56, p. R6), the report lists every one of the user organizations until February 1956, including geographic location of the installation where used, the isotope used, the year of the license and the purpose for which the license was granted. Company and subject indices are also provided. The report is based on the records of AEC's Isotopes Extension at Oak Ridge, and is available from the Forum.

About the Industry

A $2-million radiation physics lab will be built by DuPont at its Wilmington, Del., experimental station. To provide additional facilities for long-range research on the measurement of radiation and its absorption in various materials, it is expected to supply fundamental data for radiation studies now being conducted in various departments of the company. It will be operated by the DuPont engineering department and will be staffed by radiation specialists. Construction on the two-story building is scheduled to start at once on the eastern side of the station; completion is set for January 1958. DuPont emphasizes that although it designed and built the Hanford and Savannah River plutonium reactors and still operates the latter group for AEC, its direct interest is not in power reactors but in the effect of radiation on reactions involved in chemical manufacture.

●

Pictured here is the heart of a new division of the Budd Co. called Nuclear Systems, which will provide "complete systems or any parts thereof containing nuclear materials as an essential part of



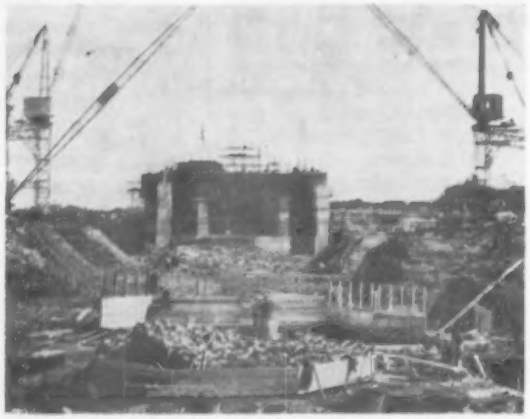
the system." The radiation facility shown will allow fabrication and use of strong radioisotope sources, in excess of 10,000 curies; it is believed to be the only commercial source of supply for such high-intensity sources in the country. In the center is a 36-in. high-density-glass shielding window looking into a heavily shielded hot cell; a closed-circuit TV system gives the operator a side view of his manipulations with an Argonne No. 8 master-slave. Budd hopes to find a considerable market for Co^{60} and other irradiation units for studies of radiation effects on industrial products and processes. It will inventory the more common long-lived isotopes in bulk form to expedite fabrication of sources to order; sources will be available for therapy, radiography, gagging, research irradiation units, etc. Budd also will design and build equipment for controlled exposure of such sources, including instrumentation and control apparatus.

●

Kennecott Copper Co. is entering zirconium production, and has engaged Horizons Inc. as consultants in the design, erection and operation of a pilot plant in Bedford, a Cleveland suburb. This marks the first non-government-sponsored production of Zr. Horizons has developed a number of patents covering zirconium metallurgy. Kennecott is also teaming with Koppers Co. to propose to AEC a 5,000-ton/yr uranium feed materials plant.

ROUNDUP

THIS 2-HIGH/4-HIGH COMBINATION rolling mill, built by Stanat Manufacturing Co., NYC, is used at Babcock & Wilcox's nuclear facilities plant at Lynchburg, Va., as a utility mill for experimental rolling of small pieces. Ingots are heated between passes in electric furnace (left). Similar mills have been built with automatic roll-changing mechanisms activated by remote control, permitting operation under dry-box conditions; one such is at Argonne, another has just been ordered by Britain's Atomic Energy Authority. Other such mills are in use in nuclear establishments in Belgium, Spain



ANOTHER NUCLEAR POWER STATION is rising in Britain: a four-reactor station at Chapel Cross near Annan in SW Scotland. Reactors will be "Chinese copies" of Calder Hall units. Like Calder Hall, Chapel Cross will be an Atomic Energy Authority—not a Central Electricity Authority—facility, with primary emphasis on plutonium production; nevertheless, Chapel Cross will supply 160 Mw net to national grid. First reactor is to be completed in 1959, last in 1961. No. 1 reactor being erected in middle distance towers over concrete forms for biological shield of No. 2 in foreground

Parley Asks More Nuclear Facilities for Use in South

Recommendations for "a long-range regional program to establish one or more strategically located nuclear test facilities" in the South "for carrying on industrial work in nuclear technology in the region" highlighted the conclusions of a special conference held last month in St. Petersburg, Fla. Called to advise the governors of 16 Southern states from Delaware to Texas on establishing a broad joint plan for regional development of nuclear energy, the conference brought together 200 technical, industrial, and educational leaders for four days of study and discussion. More than a score of recommendations resulted which, together with supporting findings, will be presented to the Southern Governors Conference this month.

The idea was first proposed by Gov. LeRoy Collins of Florida to the SGC in October 1955. The conference entrusted planning and development of the program to the Southern Regional Education Board, a central agency SGC had set up originally to pool the region's higher education facilities; it was SREB that convened the work conference. First step under the plan was to find out what the South can do in applying nuclear energy in industry, agriculture, power, public health and medicine.

The key recommendation, for regional nuclear test centers, provides that these laboratories be provided with a minimum technical operating staff and be adequately equipped to permit use of the facilities to capacity by private industry for research and development on nuclear problems. Goal is to increase the utilization of nuclear energy by industry in the Southern states. In addition, it was urged that a regional program be set up to disseminate to Southern industry information on actual experience and potential benefits of nuclear technology to industry, including the use of regional industrial conferences. The working groups also called for introduction of a broad program of public information on nuclear energy, and for expansion of the Oak Ridge Institute of Nuclear Studies.

Other recommendations included:

Manpower and education. Particular attention should be given to improving training in science and mathematics at the high school level by offering necessary incentives to obtain and hold competent teachers; motivating students to enter science professions, and requiring sounder science and math curricula in high schools.

Public health. Responsibility for health and safety matters related to the increasing use of nuclear energy should be clearly delegated to the single state agency normally responsible for public health. Adequate training facilities must be established to meet the acute shortage of trained personnel in the field of radiological health.

Nuclear power. For the "orderly economic development of commercial nuclear power in the South," the states should continue to rely on existing power systems and manufacturers.

Public information. In undertaking "aggressive action" to improve dissemination of public information on peaceful nuclear applications, existing state agencies should be utilized to the fullest.

Medicine. An information center with consultant services should be set up within the framework of an existing regional agency to collect and disseminate information that can aid expansion of the field of nuclear medicine, and to foster grant-in-aid programs for support of research, and training in the field.

Agriculture. Regional radiation facilities maintained cooperatively by AEC, Oak Ridge National Laboratory, the University of Tennessee and state agricultural experiment stations should be expanded and more widely used. A specialized training program in nuclear energy for agricultural scientists should be instituted. The states should make available funds for establishment and operation of a plant irradiation facility for research and teaching in genetics and plant breeding. This last bore immediate fruit when Gov. Marvin Griffin of Georgia authorized such a facility for the state agricultural college.

Reactor News

Prototype SRS to be built at Windsor. Combustion Engineering will build a $10-million Submarine Reactor, Small, at its new Windsor, Conn., nuclear engineering laboratory. Called S1C under the new Navy nomenclature, the reactor will be housed on a 530-acre site to be leased to AEC for 40 years for $1; like the Westinghouse submarine reactor prototype in Idaho and that of GE at West Milton, N. Y., S1C will be installed in a steel replica of a submarine hull section. All power equipment necessary for propulsion, including complete instrumentation, will be provided as on shipboard. Combustion, third major contractor in the submarine reactor program, is specializing in engines for subs considerably smaller than *Nautilus*.

Fuel element fabrication in Canada. AMF Atomics (Canada) Ltd. has the first long-term contract given private industry in Canada to make fuel elements for Atomic Energy of Canada Ltd. The firm will build a 30,000-ft² plant—first unit of a large nuclear facility—on a 30-acre site at Port Hope, Ont., to carry out the contract. Construction is to begin shortly, and the plant is to be operating at full capacity by early '57.

APPR on last lap. Construction on the Army Package Power Reactor at Ft. Belvoir, Va., is 58% complete, AEC told NUCLEONICS. The building is nearly finished, vapor container and biological shield are finished (NU, Aug. '56, p. R9), turbogenerator and condenser are installed, much of the electrical installation is completed. Secondary piping is now being connected and welded; the reactor vessel and pressurizer are being made at Alco's Dunkirk, N. Y., works, and the core at Oak Ridge. Schedule calls for installation of fuel elements and control rods in late December or early January, noncritical testing, cleanup and final examination of components in time to permit going critical prior to March 1. After low- and high-power tests, a 700-hr test will be run; feeling is that the contract provision for this to be completed by July 10 will be met.

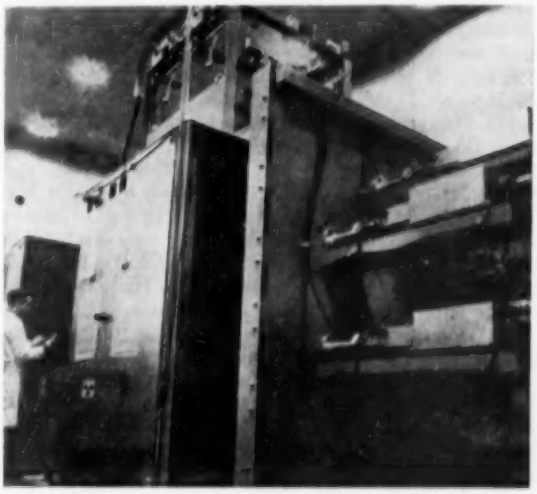
Daystrom to build Quehanna reactor. The contract for Curtiss-Wright's 1-Mw swimming pool reactor at its new research center at Quehanna, Pa., has gone to Daystrom who will build the reactor structure, control rod drives, and instrument bridge. The unit is a Chinese copy of the Penn State reactor, and is to be completed in early spring. Leeds & Northrup is said to have gotten the contract for the instrument console.

New sphere contract let. Chicago Bridge & Iron Co. will build the 190-ft dia. steel sphere to house Commonwealth Edison's Dresden station boiling water reactor near Chicago. Second only to the West Milton, N. Y., reactor sphere in size (also built by Chicago Bridge & Iron), it will be completed by early 1958; the 180-Mw plant, being built by GE, is to be in operation by 1960. Total weight of the sphere will be 3,000 tons, total volume 3,590,000 ft.³

Endurance record for sub reactor. The *Nautilus* prototype propulsion plant at the Idaho testing station, S1W (formerly STR), ran at full power for 1,600 nonstop hours—more than 66 days and 66 nights, the equivalent of a full-speed trip about 1½ times around the globe. The run was made on a single uranium charge and used only a part of it, having "many hundreds of hours of full operation" still available. A diesel-powered sub would have burned 1.6-million gallons of fuel on an equivalent run. *Nautilus* itself, still operating on its original charge (NU, Aug. '56, p. R12), has not cruised nonstop longer than 206 hours.

Dravo gets PWR contract. Westinghouse has picked Dravo Corp. of Pittsburgh as installation contractor for the Shippingport PWR. The job will include installing the 200-ton pressure vessel, steam generators, pumps, water purification system, and electronic controls. Dravo, which is starting work on the multimillion contract at once, will prefabricate some of the piping assemblies at its Marietta, Ohio, pipe shop.

Hanford's new PCTR. A new, $200,000 test reactor—the Physical Constants Test Reactor—has been placed in operation by GE at the Hanford Works. The graphite reactor is used to evaluate methods of constructing uranium fuel pieces and distributing them within present reactors, and may also help suggest improved designs for new reactors. It is part of a program of research into chain-reaction physics, aimed at producing fissionable materials more efficiently. PCTR replaces subcritical test reactors previously used at Hanford, and, being critical, develops a higher neutron flux and gives more accurate results. Further, it does not need to be



disassembled after each test, as did the subcritical machines. It is built (*see cut*) in two large blocks that can be moved apart to expose the central core: a 7-ft cube of graphite, acting as moderator, contains a 2 × 2 × 3 ft central cavity. Lattices of fuel of various kinds, sizes, and shapes and in various geometrical arrangements can be inserted in the cavity; the operator then moves the end block snugly against the central section, and measures resulting operating characteristics on recording instruments in a control room shielded by 2-to-5-ft concrete walls and roof.

Idaho is ALPR site. The Argonne Low Power Reactor will be built at the Idaho reactor testing station, AEC has decided. Construction of the 200-kw boiling water reactor (NU, March '56, p. 22) will start late this year; cost is estimated at $1,225,000. Pioneer Service and Engineering Co., Chicago, is providing architect-engineer services for the non-nuclear components for the plant, which is being designed for remote military installations.

More expansion at NRTS. A $1.6-million expansion of the assembly and maintenance building in the Aircraft Nuclear Propulsion area will include a 150 × 285-ft addition to the existing building and a second floor over part of it; bids are to be opened Sept. 12. C. W. Watkins & Son, Boise, got the contract to build a balcony in the MTR building (NU, Aug. '56, p. R9) with a $15,971 bid.

Report from Britain

LONDON

With bids due in October for the first two nuclear power stations for the Central Electricity Authority, there is considerable speculation in Britain on how greatly designs for the four groups will depart from that of Calder Hall, which was never optimized for straight power production.

But it is pretty certain from a round-up of some of the research departments that pressures of 200 psi—twice that of Calder Hall—and temperatures around 500–550° C, which are now being clocked on the development rigs, are pretty close to design specifications.

These gas conditions indicate that the construction firms are prepared to weld plate on site much thicker than the 2-in. low-carbon manganese alloy used at Calder Hall. At least one company proposes 4-in. plate. Another is known to be submitting a design using 3-in. plate in a sphere-contained reactor that will have a firm output of 300 Mw. Observers believe this to be the (British) General Electric Co. group bid, as its structural member, the Motherwell Bridge and Engineering Co. Ltd., is building the sphere for the Dounreay fast reactor.

The four groups bidding include: the Nuclear Power Plant Co. Ltd. (the Parsons, Reyrolle, Whessoe, Head-Wrightson et al. group); General Electric Co. and Simon-Carves; English Electric, Babcock & Wilcox and Taylor Woodrow; and Associated Electrical Industries and John Thompson, Ltd. The plants they are bidding on will be the first power-only stations (NU, Nov. '55, p. 60; Aug. '56, p. R11), unlike Calder Hall where plutonium is the goal and power is a byproduct.

The security clamp imposed by most of the companies now even includes monitoring of incoming phone calls. Group research teams, numbering around 200–300 have been working night and day on the two most vital problems: metallurgy of can materials, and the various phases of heat transfer. But several important advances in magnesium metallurgy are not to be fully reported until the Calder Hall symposium in November.

A new magnesium alloy called Magnox, containing beryllium, calcium and aluminum, is probably the most significant. It is the outcome of a long search by AEA metallurgists to stabilize the oxide of magnesium at elevated temperatures in a CO_2 atmosphere with a CO and H_2O content. Apparently oxidation of pure magnesium can proceed at penetration rates around 0.004 in./day in such an environment at temperatures as low as 200–300° C. The beryllium and calcium content reach up to 1% each, the calcium being largely responsible for the improved creep and weldability characteristics of the alloy. The Al assists the introduction of the beryllium into the solution.

GEC is using similar alloy. But this company told NUCLEONICS that the higher gas pressures and temperatures used in its reactor render the oxidation rate less critical but aggravate the creep problem with the fins. This made the stress-and-corrosion properties all-important, and the company has developed a rig which, it claims, enables these two processes to be examined simultaneously for the first time. Findings have led to a modification of the alloy that at the same time tends to inhibit the ability of magnesium to vaporize through its surface oxide.

Apart from having a low neutron capture, another advantage of magnesium is its almost perfect compatibility with uranium. This obviates need for an anti-diffusion barrier between can and rod. Using aluminum cans, catastrophic diffusion between can and rod—causing bursting of the can by the eutectic formed—was both first observed and remedied at Harwell during the Easter holiday of 1947. This was revealed to NUCLEONICS by L. M. Wyatt, who together with H. Finniston—the two chief metallurgists of AEA—and a third man worked shifts round the clock for several days. The remedy is still classified but apparently is an anodizing process costing less than 1% per can. (Pimpling was first noted in a U. S. report published some months before the Harwell work.)

While magnesium is compatible with uranium, it is violently reactive under operating conditions to tin, lead and many other metals, trace quantities of which could possibly be present. As normal anodizing is not effective, GE metallurgists have perfected a special anodizing process using an undisclosed metal fluoride in the electrolyte. It is claimed that at operating temperatures of 550° C, the can surface obtained is fully stable when in contact with the worst offenders—lead and tin. So far it is not thought that any such protection was provided for the Calder Hall cans.

It is also just revealed that the cans used in Calder Hall have transverse fins (at right angles to gas flow) which greatly increase heat-transfer coefficient for a negligible rise in pump horsepower. Originally the cans had longitudinal fins parallel to the gas flow, or only slightly twisted after extrusion. But P. Fortescue, who hit upon the transverse arrangement, told NUCLEONICS that the transverse temperature distribution across the duct proved "shockingly non-uniform." There was a perpetual hot gas core clinging to the roots with a relatively cold annulus outside. Attemps to "stir it up," he said, began with the use of clip-on deflectors, the arrangement that finally appeared to give the best heat transfer for given pressure drop being in effect equivalent to placing the fins transversely. A water and aluminum powder rig on which this flow pattern was simulated revealed the existence of two contrarotating vortices behaving in the manner of a gear pump between adjacent fins. These generate high scrubbing velocities across the fin, mix the gas generally and greatly increase the heat-transfer coefficient for a negligible rise in pump horsepower.

The Calder Hall cans, which are 4 ft long, have a single start helical fin 7/32 in. deep by 1/8 in. thick, milled from solid extruded bar; wall thickness is 1/16 in., pitch about 1/8 in. and the rod diameter is 1.15 in. A radial clearance of 0.007 in. is closed by the coolant pressure.

Impact extrusion techniques are being developed generally to form the can. GEC appears to favor multi-start wide-angle helical finning to transverse finning and has produced some cans with both fin and can extruded—helix angle being obtained by twisting. Sealing the end caps is commonly done by an automatic argon arc-welding cycle with the can rotating. There is a likelihood that both Harwell and GEC at least enclose an He capsule before sealing as a fault-monitoring agent.

Over-all impression is that the scope and intensity of the research effort made by the four groups has no precedent in British industrial history. Design departments often have worked 24 hours a day, seven days a week, during the last 12 months. GEC alone has spent $4½-million so far in preparing its 2-million-word bid. This includes in their case an analog computer on which the whole operating cycle of the reactor has been programmed. In this project a significant section of British industry has had to stretch commercial prudence beyond conventional limits. As GEC director A. Lindley put it, "There is no pulling out now."

World News

Brazil fixes pool site. After some deliberation (NU, May '56, p. 23), Brazil has decided on São Paolo as site for the 5-Mw swimming pool Babcock & Wilcox is building for her. It will be located on the new campus of the University of São Paolo in the suburb of Jaguaré, about 5 miles SW of the city center. A new Institute of Atomic Energy has been established to operate the reactor. William M. Breazeale is project engineer for B&W.

New French liner to be atom-convertible. For several years France has been planning a *Normandie*-like superliner to replace the aging *Ile de France*. Last month the French Line disclosed the 30-knot, 55,000-ton *France* would be built with engine-rooms so designed that the ship's eight boilers could be removed and replaced by reactors if nuclear power should become economic. The $78-million ship is to be laid down shortly at the Penhoët yards in St. Nazaire for launching in 1960. This is the first decision for even deferred use of reactor power in a major passenger liner; the U. S. Lines considered and turned down nuclear power for the projected sistership to the *United States*.

Belgian reactor operating. The first research reactor at the Mol nuclear center (NU, Feb. '56, p. 13) went critical with a very flat first loading—the core length was about half the diameter and amounted to 18 tons natural uranium. Critical experiments now being run show that optimum critical loading will be ~15 tons.

West Germany finds U ore. Promising deposits have been uncovered along the iron curtain border. Richest are in the Fichtel mts near Selb at the Bavarian-Czech-Soviet zone frontier juncture; at Weissenstadt, one of 30 locations in this area where deposits exist, the ore assays 40 gm/ton. Uranium has also been found in three other areas: in the Bavarian forest along the Czech frontier and in Upper Franconia; in the Brocken district of the Harz mts, and in the Black Forest. The frontier deposits are offshoots of the rich pitchblende veins in the Erzgebirge between Czechoslovakia and East Germany which is now one of the Communists' chief sources. None of the West German deposits rivals those of the Belgian Congo, Canada, or Colorado, but they do total enough to make West Germany perhaps self-sufficient; the government estimates a yield of 30 tons of U^{308}.

Germany getting Spanish U. Bonn hopes for a successful conclusion to discussions initiated by Atomics Minister Franz Josef Strauss in Madrid recently for German participation in mining of Spanish uranium ore. Germany wants foreign ore of higher concentration (such as found in Spain) which, mixed with lower-grade German ore, would make processing more economical. Outlook is for setting up of joint companies using German machinery and trained specialists, Spanish labor and capital. Concentrates would be processed in Germany, some might be returned to Spain.

A-ship plans in Japan. The Transportation Ministry has drafted plans for completion of two nuclear-powered ships by 1966. Propulsion plants are to be 20,000–30,000 hp, one imported, one built in Japan. Submarines are preferred, but if the cost is prohibitive surface vessels will be built. A basic research program is to be launched next year (the Ministry is asking $638,000 in the 1957 budget), and a research reactor built or imported within five years.

Advances in Israel. Another new step is reported in Israel's efforts to assure a domestic uranium supply: a cheap method for detection of underground U deposits by "indirect" means where natural sources of water and gas occur. Last year Israel reported development of a new process for extracting U from phosphates found in the Negev.

Trombay pool critical. The first reactor in Asia reached criticality on Aug. 4 under dramatic circumstances as 50 scientists and engineers, almost marooned on Trombay Island in Bombay harbor by lashing monsoon gales, worked around the clock. Difficulties, in addition to bad weather, had included deformation in transit of fuel elements shipped from Britain. The $630,000 reactor moves horizontally in a 28 × 10-ft pool of 8½-ft concrete, which stands in a 100 × 50-ft hall 70 ft high. The core is a 2-ft cube containing 25–30 MTR-type fuel elements supplied by the UK under a bilateral signed last year. The reactor will operate at 1 Mw. In addition to experimental channels, a graphite thermal column 6 ft square is provided at one end of the pool; at the other end are facilities for shielding experiments. Automatic safety devices will scram the reactor if power fails, excessive heat is generated, or certain instruments fail. The larger CIR (NU, June '56, p. 23) is under construction also on Trombay Island. (*See photo p. R6.*)

Medical center for Taipei. A $100,000 Atomic Medical Center building has been completed at the capital of Taiwan (Formosa). It has no equipment yet, but Prof. Wu Ching, president of the Chinese Radiological Society, now studying in the U. S., plans to buy a Co^{60} machine and a 2-million-volt X-ray machine next year from American manufacturers.

East European news. Foundation work and the first above-ground installations are proceeding on Hungary's research and isotope producing reactor—first Soviet reactor to be built outside the USSR—at Csillebérc in the hills overlooking Budapest, near the site of the Central Physical Sciences Institute. It is slated to go into operation at the end of 1957, and is said to be of "the same type used in Moscow with only a few detail changes necessary because of particular Hungarian requirements." Bulgaria has started basic construction on her research-and-isotope reactor, and has also altered Soviet blueprints. She plans to specialize in nuclear biology, and special channels for biological research will be provided. Special construction precautions are being taken because of the earthquake danger at the undisclosed site. Yugoslavia is also in the construction phase on a larger Soviet research reactor of the type Russia is supplying also to Peiping. Czechoslovakia (NU, April '56, p. 19), Poland, and Rumania are also to get Russian research reactors. Meanwhile Hungarian Premier András Hegedüs declared that his country's first power reactor would be started during 1957 for completion by 1960; "the Soviet Union has assured us of her fullest assistance in this project," he said. Furthermore, "several high capacity atomic power plants should start operations in our country" during the third (1961–65) five-year plan; finally, he promised that these plants would be fueled by Hungarian fissionable materials. Mass-production of nuclear instruments has started in Hungary, is soon to start in Czechoslovakia and Poland. East Germany reports discovery in Thuringia of uranium deposits described as "the largest in Europe" that will take 15–20 years to mine; the 11,000 inhabitants of Ronneburg are to be resettled.

ROUNDUP

News in Brief

New licenses. Battelle last month got an operating license for its Columbus, O., pool research reactor. Aerojet-General Nucleonics got a construction permit for its prototype AGN-201 (*See p. 100*). And the National Advisory Committee for Aeronautics (NACA) applied for a $5-million tank-type research reactor using fully-enriched U^{235} for ANP studies at its Lewis Flight Propulsion Laboratory at Sandusky, O.

AEC seeks magnesium . . . Oak Ridge has asked for 2,000–3,000 tons of Mg in the 12 months beginning next July 1.

. . . and contracts for uranium. AEC seems to be moving to clean up its backlog of pending contracts for U mills. Four were signed within a few weeks: with Texas Zinc Minerals for a large mill at Mexican Hat, Utah; with Dawn Mining Co. at Ford, Wash., 28 mi N of Spokane; with Lost Creek Oil & Uranium Co. at Split Rock, Wyo., and with Union Carbide Nuclear at Rifle, Colo. (NU, July '56, p. R5). A fifth accord is "imminent" with Lucky Mc-Utah Construction Co. in Fremont County, Wyo., and others are still pending. Basic understanding has been reached with Vitro for a $1.2-million expansion at Salt Lake City using a new solvent extraction process. The $3-million, 400-ton/day Dawn processing mill will be the first approved by AEC using ion exchange columns. Western Knapp Engineering Co. of San Francisco will build both the Dawn and Lost Creek mills, starting at once for completion in a year.

Radiation research at Mellon Institute. The Pittsburgh research organization is planning a major research effort on radiation, and has established a department to carry on the work. Former Army Chief of Staff Matthew B. Ridgway, now chairman of Mellon's trustees, said the Institute has bought a 3-Mev Van de Graaff from High Voltage Engineering Corp., and has engaged Robert H. Schuler of Brookhaven to head the radiation research department. The work will cover both basic studies on the nature of radiation and investigation of practical applications in chemical processing, "cold" sterilization, and other fields.

New contract for Fernald. National Lead Co. has received a four-year extension of its contract with AEC to operate the Feed Materials Production Center at Fernald, Ohio. The new pact runs to June 30, 1961; annual estimated operating costs are $38-million.

Controlled fusion course. Stevens Institute of Technology, Hoboken, N. J., is offering a 15-week graduate course in controlled production of energy by thermonuclear fusion. The course, believed to be the first ever given in this field, will be taught by the new physics department head at Stevens, Winston H. Bostick, fresh from an AEC thermonuclear research project at the University of California Radiation Laboratory; it will cover theory, proposed processes, techniques and problems involved in using fusion energy.

Security group expands. The Scientists' Committee on Security Inc., an independent voluntary group set up early this year, is planning to expand its activities in the field of science and security. The committee seeks to act as a clearing house for information and responsible scientific opinion on matters of information security and personnel security, and attempt to answer individual inquiries in this field (2153 Yale Sta., New Haven, Conn.). Other functions include cooperation with government agencies in establishing realistic security programs that safeguard both national security and individual rights; fostering of better popular understanding of the relationship of science and security; and undertaking of special studies and reports in this area.

Neutron generator for U. of Arkansas. The chemistry department at the U. of Arkansas is installing a 400,000-volt positive ion accelerator to produce 14-Mev neutrons for research and graduate instruction in nuclear science. AEC is supplying the cost of the instrument and the university is providing the housing; over-all cost will be $100,000. In subsequent years neutrons from the $H^3(d,n)He^4$ reaction may be used to activate a "pickle-barrel" reactor.

GE expands at Schenectady. A $2-million expansion of GE's facilities for manufacturing and testing canned motor and electromagnetic pumps for the nucleonics industry has begun. Employees engaged in this work "will almost triple" within 12 months.

Kidde studying shielding for Army. A contract for a "field expediency shielding study" has been given Walter Kidde Nuclear Laboratories by the Army Corps of Engineers. Objective of the study, to be completed by January, is to gather basic data on shielding against neutron and gamma radiation using materials available in military field operations.

General Atomic philosophy. When General Dynamics Corp. dedicated the San Diego site of its General Atomic division's $10-million pure and applied science lab, division research director Edward C. Creutz said the lab's purpose will be to combine learning with doing—that is, basic research with technological development. Under the second heading, he said, GD is working on several kinds of reactor problems, including an effort to create reactors "intrinsically so safe that they could be installed in any community, in any university, in any country." Under the first, the program will include attempts "to understand the electronic and nuclear structure of materials in a search for things with better high temperature strength, better resistance to the effects of radiation, and better corrosion resistance. Our basic research will also include work on the nature of the hydrogen atom . . . because some day in the future our energy may come from the fusion of hydrogen atoms in controlled thermonuclear reactors. We shall also carry out basic research on the process of fission of the heavy nuclei, for although one knows how to make a wide variety of chain-reacting devices, there is still much unknown about the real nature of nuclear fission." At the division's temporary headquarters, meanwhile, studies of reactor systems and other nuclear projects are underway, including a study on commercial ship propulsion.

Summer training for more engineers. A second, supplementary summer school for engineering college faculty members is being established at Brookhaven National Laboratory, in addition to the original one at Argonne (NU, Jan. '56, p. 16). The BNL program will accommodate 30 additional candidates; 22 institutions will be represented in the first class. The first Argonne school had a capacity of 60, and more than 160 qualified applications were received. Basic aim of the program is to expand the number and scope of engineering courses offered in the nuclear field. Meanwhile, applications are due Nov. 1 for the fifth session of Argonne's International School of Nuclear Science and Engineering, starting Feb. 4.

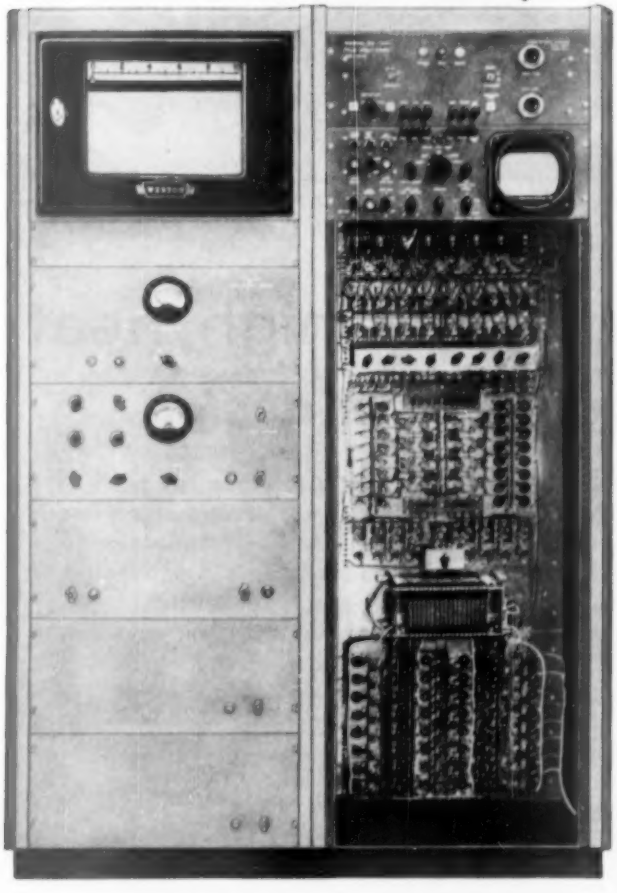
SEE YOU AT THE TRADE FAIR OF THE ATOMIC INDUSTRY—CHICAGO, NAVY PIER—SEPT. 24–28

RCL Mark XX

Multi-Channel Analyzer

model 2603

A 256 Channel Analyzer based on the Argonne National Laboratory Design



- Permits automatic subtraction of background from the spectrum read out.
- Permits section storage for separate isotopes. Average dead time of the counting channels is reduced when only the first 128 channels are used.
- Provision for decimal printout with auxiliary circuit is available.
- Records a permanent plot of the spectrum.
- Analyzes approximately one million counts per minute—acceptance counting rate up to five million per minute—without appreciable data distortion.
- Ease of maintenance aided by oscilloscope readout.
- Information permanently stored in magnetic toroids—data cannot be lost through power or component failure.

Specifications

1. 256 channels, each with 65,536 count capacity. **2.** Linearity 0.2% of full scale (except first 2 channels). **3.** Channel dead time 20 microseconds plus 0.5 n microseconds, where n is the channel number. Average dead time is less than 80 microseconds. **4.** No channel width adjustment needed—no channel width drift. Positional drift small and uniform. **5.** Channel width approximately 0.2% of full scale. **6.** Cathode ray tube display of data available during accumulation and readout — clearly shows the data in each channel. **7.** Permanent record of accumulated data available with precision pen recorder. **8.** 100-kc pulse generator for decimal conversion. **9.** 1000 VA Sola transformer for voltage regulation. **10.** Standard power cable has three-prong connector with provision for grounding.

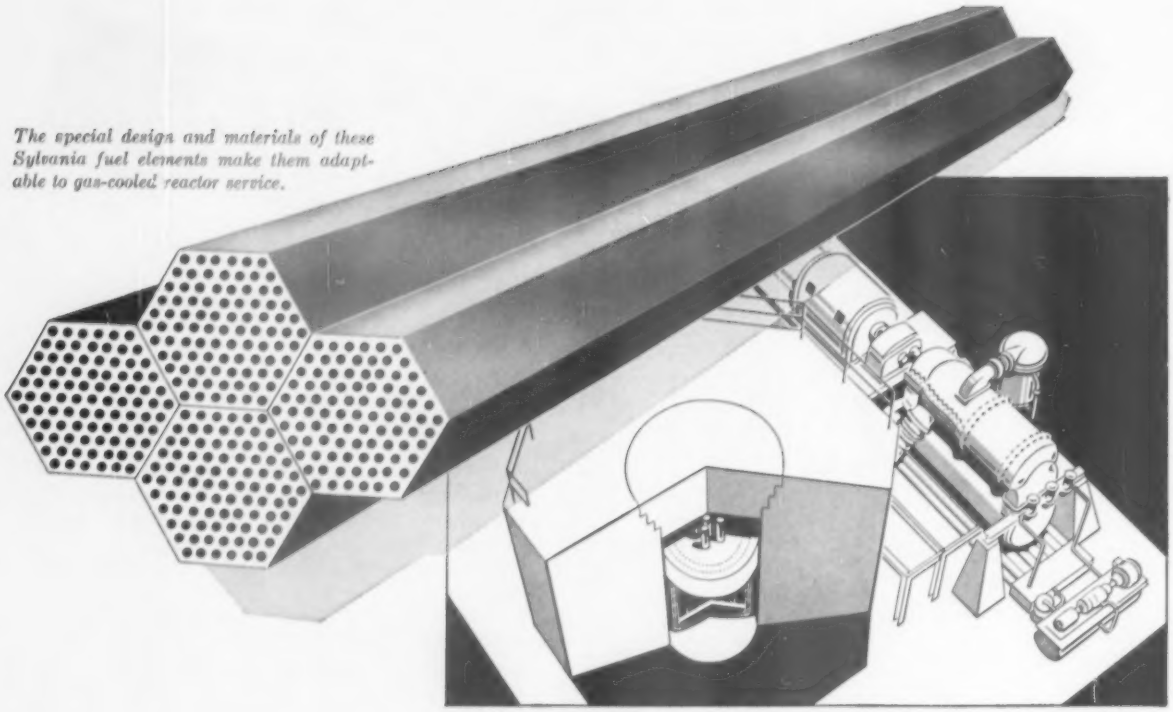
For full details write to Dept 196

RADIATION COUNTER LABORATORIES, INC.

RADIATION COUNTER RCL LABORATORIES

Nucleonic Park SKOKIE, ILLINOIS

The special design and materials of these Sylvania fuel elements make them adaptable to gas-cooled reactor service.



A typical closed cycle gas-cooled reactor power plant system design, utilizing a gas turbine translation unit. Drawing courtesy of American Turbine Corporation and Ford Instrument Company.

Gas-cooled reactors and high heat

...a problem in fuel element design

THE development of nuclear-powered gas turbines promises to open up important new fields of practical application for atomic energy. If postulated economies are realized, the gas turbine will prove to be an ideal mobile power source for oil tankers and other seagoing vessels. The gas turbine promises, also, to be an economical power source for small generating plants in the 5000 to 50,000 KW range.

To realize inherent economies, the gas turbine requires a gas-cooled nuclear reactor—a type that of necessity operates at high temperature. Fuel elements of customary design are unsatisfactory for this service because of the high operating temperatures encountered. To meet this problem, Sylvania has developed a series of special high-temperature elements that can be adapted to gas-cooled reactor service which calls for fuel operating temperatures of 1200 F and above.

If you would like to investigate the practicability of similar reactors for your own applications ... *remember that the key to economical operation is the fuel element and fuel reprocessing.* Our technical and scientific staff will gladly answer any questions you may have in this area. Write for your copy of: *Sylvania Atomic Fuels and Reactor Components.*

SYLVANIA ELECTRIC PRODUCTS INC.
Atomic Energy Division, P. O. Box 59
Dept. H55V, Bayside, New York
In Canada:
Sylvania Electric (Canada) Ltd.
University Tower Building, Montreal
Sylvania International Corporation
14 Bahnhofstrasse, Coire, Switzerland

SYLVANIA

ATOMIC ENERGY DIVISION

LIGHTING • RADIO • ELECTRONICS • TELEVISION • ATOMIC ENERGY

SEE SYLVANIA IN BOOTHS 109–110 IN THE 1956 TRADE FAIR OF THE ATOMIC INDUSTRY

19 tons of stainless...

all for one customer...

all for atomic power...

...and all from

CARLSON

Type 304 stainless plates abrasive cut to size and ultra-sonic tested. These plates total 19 tons and range from 1 to 6 inches thick.

G.O. CARLSON, INC. *Stainless Steels Exclusively*

THORNDALE • PENNSYLVANIA

District Sales Offices in Principal Cities

ANNOUNCEMENT

acf INDUSTRIES, INCORPORATED

ANNOUNCES THE OPENING OF
AN OFFICE IN WASHINGTON, D.C., FOR ITS

nuclear energy products division

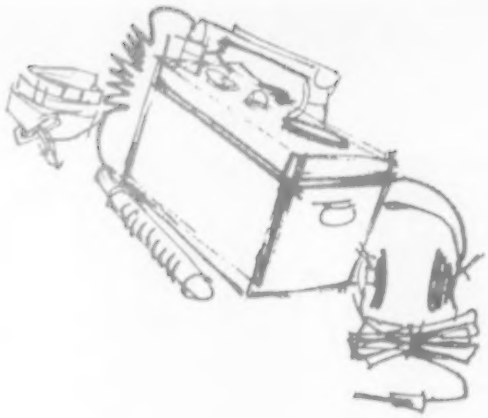
under the direction of recognized scientists and engineers of the nuclear technology field. Your inquiries relating to design and manufacture of nuclear reactors, reactor components, and custom nuclear equipment are cordially invited.

508 Kennedy St., N.W. • TUckerman 2-6440

REACTORS UNDER DESIGN AND CONSTRUCTION

5 MW CP-5 Type.....	Heavy Water Research Reactor: Massachusetts Institute of Technology
5 MW CP-5 Type.....	Heavy Water Research Reactor: Italian National Committee on Nuclear Research
20 MW ORR Type.....	Light Water Research Reactor: Reactor Centrum Nederland

See us at Booths No. 253-4, 353-4—1956 Trade Fair of the Atomic Industry

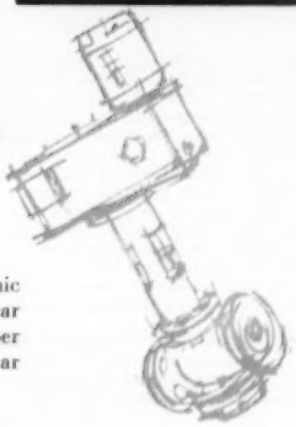


NUCLEONICS

BUYERS' GUIDE ISSUE

NUCLEONICS BUYERS' GUIDE

sells your nuclear products . . . the year 'round



The NUCLEONICS BUYERS' GUIDE, reaching out to buyers in atomic power, nuclear engineering and applied radiation, can sell your nuclear products. The BUYERS' GUIDE . . . in NUCLEONICS regular November issue . . . is the industry's one source of buying information for nuclear components, end products and services.

ACCURATE, UP-TO-DATE listing of nuclear products and their manufacturers with advertisers names boldfaced. An alphabetical list of the industry's manufacturers. Special catalogue-style advertisements for complete product reference. These are features that makes the BUYERS' GUIDE pages sell.

ESTABLISH YOUR COMPANY as a prime source for nuclear sales with an advertisement in the BUYERS' GUIDE. And your sales message will receive the added benefit of the year long use by the entire industry.

NUCLEONICS A McGraw-Hill Publication • 330 West 42nd Street • New York 36, N. Y.

five channel analyzer

with independently adjustable channels

. . Now Yours at Low Cost with Tracerlab's RLP-7 Five-Peak Analyzer

Tracerlab's RLP-7 unit is a completely integrated system for determining the relative amounts of several different isotopes.

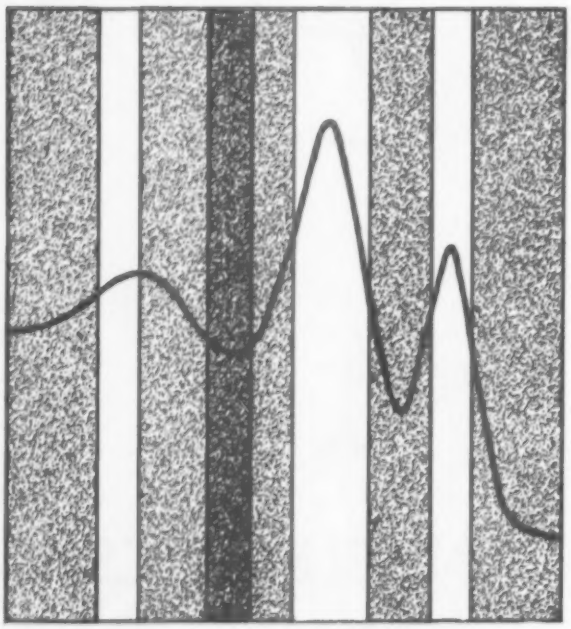
The instrument makes simultaneous routine measurements (qualitative and quantitative) of various alpha, beta, or gamma emitters present in the same material. It is also useful for general spectrum analysis. The instrument provides five independent channels, each one of which can be located anywhere on the spectrum — and each has an independently variable window width.

Five scalers accumulate counts from radiations within selected energy brackets. You set the upper and lower limits for each channel . . . for example, one channel may encompass the 1.33 Mev Cobalt-60 gamma, while another can be set at the Cesium-137 gamma energy level of 0.66 Mev, and so on.

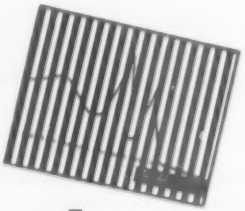
Developed in response to the need for accurate, reliable, relatively inexpensive and rugged equipment, it is a highly stable pulse height analyzer constructed on Tracerlab's unique "Building Block" principle. This design and construction combines the economy of standard unit production with the advantages of equipment custom engineered to your specific needs. The modular design enables you to add more units from time to time as your needs may require on a most economical basis. Conventional multi-channel analyzers with up to 50 channel capacity may be obtained by combining standard Tracerlab units.

Write today for Tracerlab's Radiation Research Equipment Catalog. It's a complete guide to the selection of components and many assembled systems. Prices are included.

Tracerlab offers qualified engineers and scientists exceptional career opportunities for work in the commercial applications of nuclear science.



TRACERLAB RLP-7
FIVE-PEAK ANALYZER
combines in a single instrument a shielded detector element, an amplifier, window amplifier and discriminators, high voltage supply, controls and ventilated rack mount on casters.
Price, $7310.00.



Tracerlab Kelley

Tracerlab

130 High Street, Boston 10, Mass.
2030 Wright Avenue, Richmond 3, Calif.

NEW YORK • HOUSTON • PHILADELPHIA
PARIS • CLEVELAND • LOS ANGELES
WASHINGTON • CHICAGO • OTTAWA

Worldwide services in isotopes, instrumentation, consultation and health physics.

Can ALITE solve a materials problem for you?

For designers seeking a material that possesses exceptionally high dielectric characteristics, plus superior mechanical strength and high temperature stability, Alite offers many interesting possibilities.

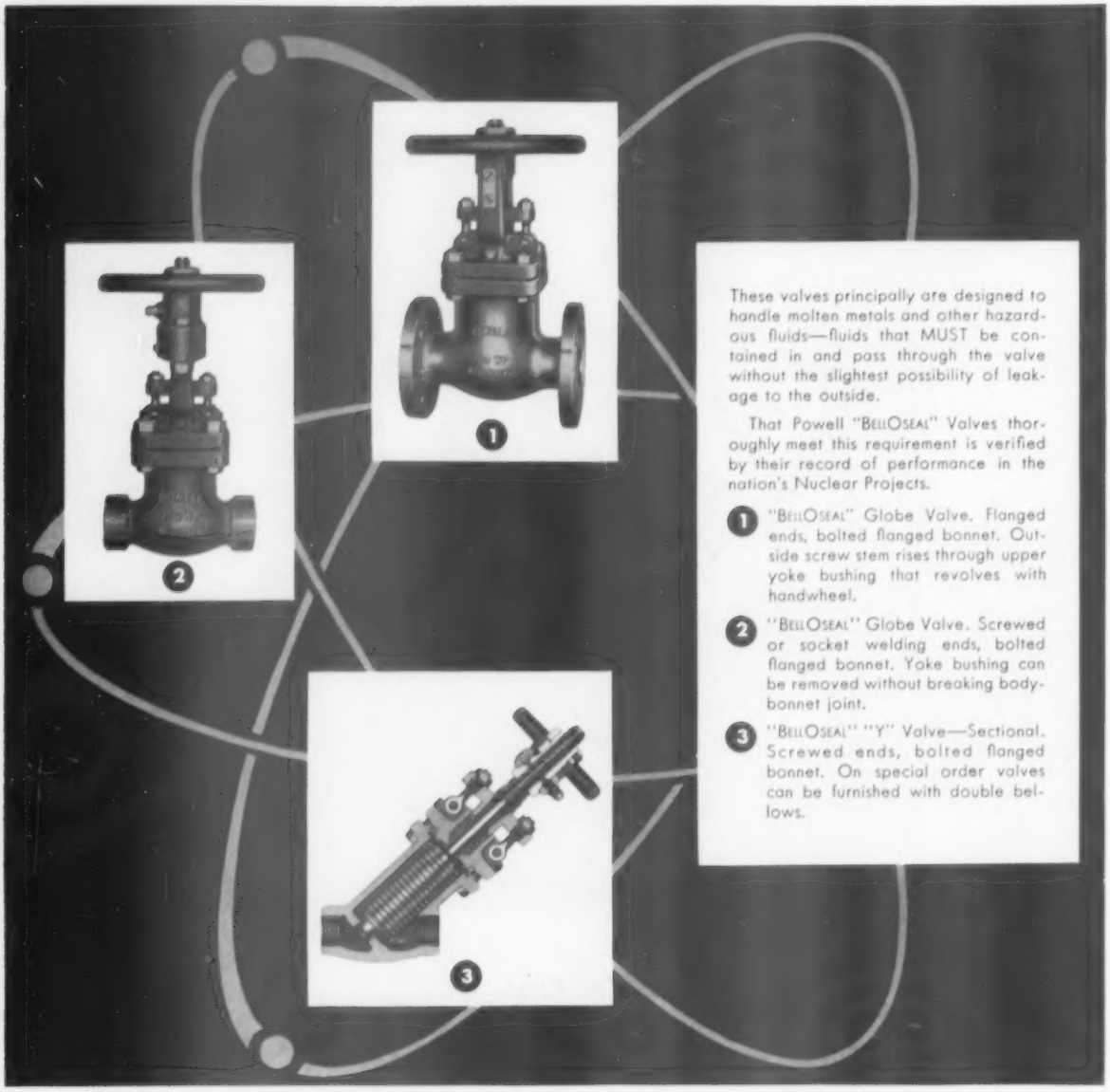
Alite comprises a series of sintered metallic oxides which we can form to practically any shape by extruding, pressing, molding or casting, and can finish to any precision you require by diamond wheel grinding. The series of Alite formulations based on aluminum oxide exhibit a wide range of excellent physical and electrical properties which make them well suited for many critical applications. Alite retains its diamond-like hardness, abrasion resistance and physical strength at working temperatures well above 2000°F. It has proved highly successful in such uses as rotating seals, pump plungers, slide valves, bearings, bushings, and extrusion dies.

Alite Formulation AE-212 is designed specifically for electronic applications. It is ideal for use as tube envelopes, as insulating supports—anywhere that a combination of high dielectric and mechanical strength is required.

If you are designing a new product or improving an existing one, you'll certainly want to explore all the advantages of Alite. Bulletin A-7 gives complete comparative data. Write for a free copy today.

U. S. STONEWARE
AKRON 9, OHIO

340E



These valves principally are designed to handle molten metals and other hazardous fluids—fluids that MUST be contained in and pass through the valve without the slightest possibility of leakage to the outside.

That Powell "BELLOSEAL" Valves thoroughly meet this requirement is verified by their record of performance in the nation's Nuclear Projects.

1. "BELLOSEAL" Globe Valve. Flanged ends, bolted flanged bonnet. Outside screw stem rises through upper yoke bushing that revolves with handwheel.
2. "BELLOSEAL" Globe Valve. Screwed or socket welding ends, bolted flanged bonnet. Yoke bushing can be removed without breaking body-bonnet joint.
3. "BELLOSEAL" "Y" Valve—Sectional. Screwed ends, bolted flanged bonnet. On special order valves can be furnished with double bellows.

Valves for use in Atomic Power Plants

. . . had to be designed to control the flow of radioactive materials. And Powell developed the valves necessary for handling liquid metals in nuclear power plants.

Constant laboratory control is maintained over the production of all Powell Valves. And in the manufacture of valves such as those pictured, this painstaking quality control becomes more important than ever. We begin our quality control with the very material of which Powell Valves are made. Then throughout manufacture, every part of every valve must pass rigid inspection. As a final step, *every Powell Valve is subjected to an actual line test.*

For complete information, consult Powell Engineers—they will be pleased to tell you about these valves as well as our COMPLETE *quality line* which has *Performance Verified.*

PERFORMANCE PV VERIFIED

The Wm. Powell Company, Cincinnati 22, Ohio . . . 110th YEAR

POWELL VALVES

BRONZE, IRON, STEEL AND CORROSION RESISTANT VALVES.

Los Alamos Scientific Laboratory is located in a delightful small city, high in the pine forests of northern New Mexico. It is a city of

Leisurely living...

and Career Opportunities

The Laboratory has immediate openings for scientists in:

THEORETICAL PHYSICS AND MATHEMATICS

Theoretical studies provide guidance and support for all of the Laboratory programs as well as conceptual designs of nuclear weapons. In addition, basic research is carried on in theoretical physics and mathematics. All these activities are supported by four modern high-speed electronic computers.

EXPERIMENTAL NUCLEAR PHYSICS

Among the facilities available are three Van de Graaff generators, a variable energy cyclotron and a number of reactors. The Laboratory is well known for its basic research in neutron and charged-particle physics and, more recently, for its confirmation of the existence of the free neutrino.

WEAPONS PHYSICS

As the nation's principle institution for fission and thermo-nuclear weapons research, the Laboratory is interested in a wide variety of problems associated with the design, development and testing of systems for the release of nuclear energy.

NUCLEAR REACTOR RESEARCH AND NUCLEAR PROPULSION

In a large area of the peacetime application of nuclear energy, the Laboratory is currently developing new research reactors and power reactors of unusual design. Several remotely controlled critical assemblies constitute neutron research tools of a unique character. The Laboratory is actively engaged in the application of nuclear energy to the new and challenging field of self-propelled mobile reactors.

If you feel you are an above-average candidate, if you want to join the scientists at Los Alamos working at the very frontiers of their field, write:

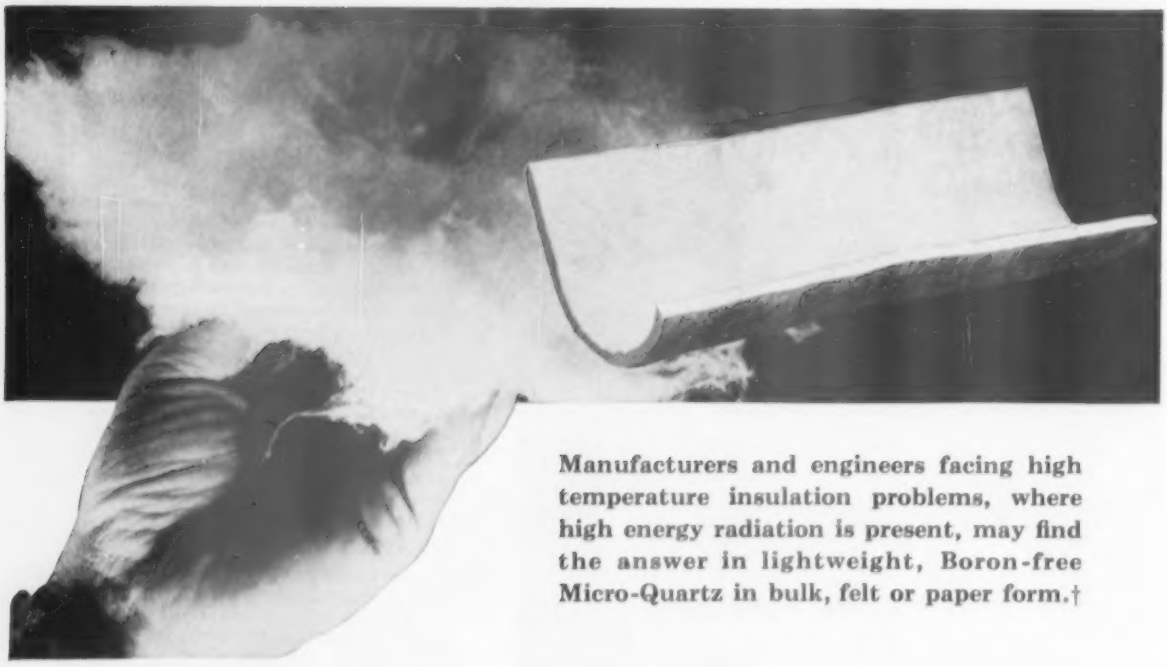
Director of Scientific Personnel
Division 1208

los alamos
scientific laboratory
OF THE UNIVERSITY OF CALIFORNIA
LOS ALAMOS, NEW MEXICO

Los Alamos Scientific Laboratory is operated by the University of California for the U. S. Atomic Energy Commission.

L·O·F Glass Fibers Company Introduces

MICRO-QUARTZ—Boron-free insulation for the 2000°-2500° Temperature Range!



Manufacturers and engineers facing high temperature insulation problems, where high energy radiation is present, may find the answer in lightweight, Boron-free Micro-Quartz in bulk, felt or paper form.†

L·O·F Glass Fibers Company announces Micro-Quartz—a remarkable, new insulation for temperatures ranging, under many conditions, up to 2500°!

Micro-Quartz is manufactured Boron-free in bulk or felt form. It is light in weight and composed of 98% quartz. It is resilient, exceptionally efficient, and resistant to vibration and air flow. Because it has no organic binder, its performance, stability, and thermal conductivity are those of the quartz fibers themselves.

The range of uses to which Micro-Quartz can be put is very broad, with possible uses in all industries working with high temperatures. It may be the answer to high temperature problems involving low heat capacity and high thermal diffusivity, frequent- or rapid-heating cycles, and problems of weight, space limitations, and vibration.

Micro-Quartz paper is made in thicknesses of 4 mils and up. Can be impregnated or coated for electrical applications.

Requests on your business letterhead for more information, and a Micro-Quartz sample, will receive prompt attention. Write: L·O·F Glass Fibers Company, Dept. 93-96, 1810 Madison Ave., Toledo 1, Ohio.

PRODUCT DATA ON STANDARD MICRO-QUARTZ SHEETS*

Average Fiber Diameter—0.75 microns or 0.00003 inches

Density—Standard nominal density is 3 lbs./cu. ft.

Weight—0.047 lbs. per sq. ft.—nominal.

Thickness of sheet—Standard nominal thickness is 3/16 inches

Width of sheet—36 inches

Length of sheet—116 inches

*Other thicknesses and densities are available. Sheets can be fabricated to fit your application.

†L·O·F Glass Fibers Company supplies Micro-Fibers only. Names of glass paper manufacturers on request.

L·O·F GLASS FIBERS
Micro-Quartz
HIGH TEMPERATURE INSULATION

L·O·F GLASS FIBERS COMPANY

TOLEDO 1, OHIO

Makers of glass fibers by the "Electronic-Extrusion" process

AGN *announces the world's first*

Mass-Produced Reactors

FEATURES:

- Prompt availability
- Complete testing before shipment
- Low capital investment
- Maximum safety
- Portability
- Low operating cost
- Location in existing buildings
- No waste disposal
- Exportable

APPLICATIONS:

- Education
- Training
- Research
- Medical diagnosis
- Industrial process control
- Tracer production
- Radiation instrument testing
- Reactor component testing

GENERAL CHARACTERISTICS, AGN 201:

CORE: homogeneous; fueled with U-235 in polyethylene moderator; quadruply sealed

CONTROL AND SAFETY RODS: positive "fail-safe" electro-mechanical operation

FLUX AND POWER: normal, 4.5 x 10^6 n/cm^2 sec at 100 milliwatts; higher flux and power available

CORE LIFE: effectively infinite

CONSOLE: provides centralized reactor monitoring and operation

INSTRUMENTATION: complete; similar to largest reactors

ACCESS PORTS: glory hole, four access ports, plus vertical thermal column

SHIELDING: completely self-contained

AGN 201 mass-produced nuclear reactors are promptly available for purchase, lease-purchase, or rental. Complete technical and application data furnished on request; write, wire, phone or cable now.

AGN SERVICES INCLUDE:

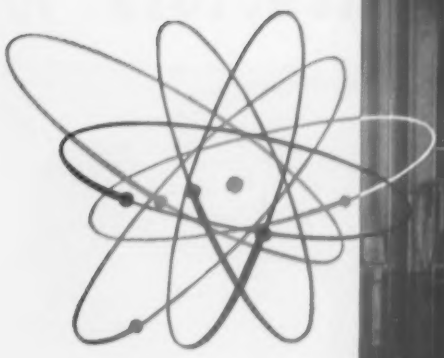
- Delivery and guaranteed operation in your laboratory
- Complete operator training
- Arrangements for required licenses

Aerojet-General Nucleonics

AGN

SAN RAMON, CALIFORNIA Cable Address: AGNU

See this Crane valve design at the 1956 Atomic Industry Trade Fair, Navy Pier, Chicago, Sept. 24 through 28. Booths 336-337.



Eight Crane all-stainless parallel disc gate valves—similar to this one, but with butt-welding ends—will be on main coolant lines in new prototype atomic power reactor plant.

AGAIN...Crane leads the way in flow control for atomic power

As the age of atomic power unfolds and expands, Crane continues to lead the way in flow control.

Crane equipment is already playing an important role in the mighty *Nautilus* and *Seawolf*—the Navy's celebrated atomic-powered submarines.

Now Crane valves are ready to make history again in the peaceful use of atomic energy—in the nation's first land-based atomic power plant.

Eight Crane stainless steel gate valves—similar to the one shown above—will be on the main coolant lines in the pressurized water reactor. Crane's broad experience in flow control for atomic power—dating from the beginning of this radically different field—assures low-cost, dependable service on this critical application.

Whether your future involves atomic energy for power or radioactive materials for processing—call on Crane for the right valves and fittings. You'll find Crane has the depth in research, engineering, and manufacturing abilities and facilities you're looking for.

CRANE VALVES & FITTINGS

PIPE • KITCHENS • PLUMBING • HEATING

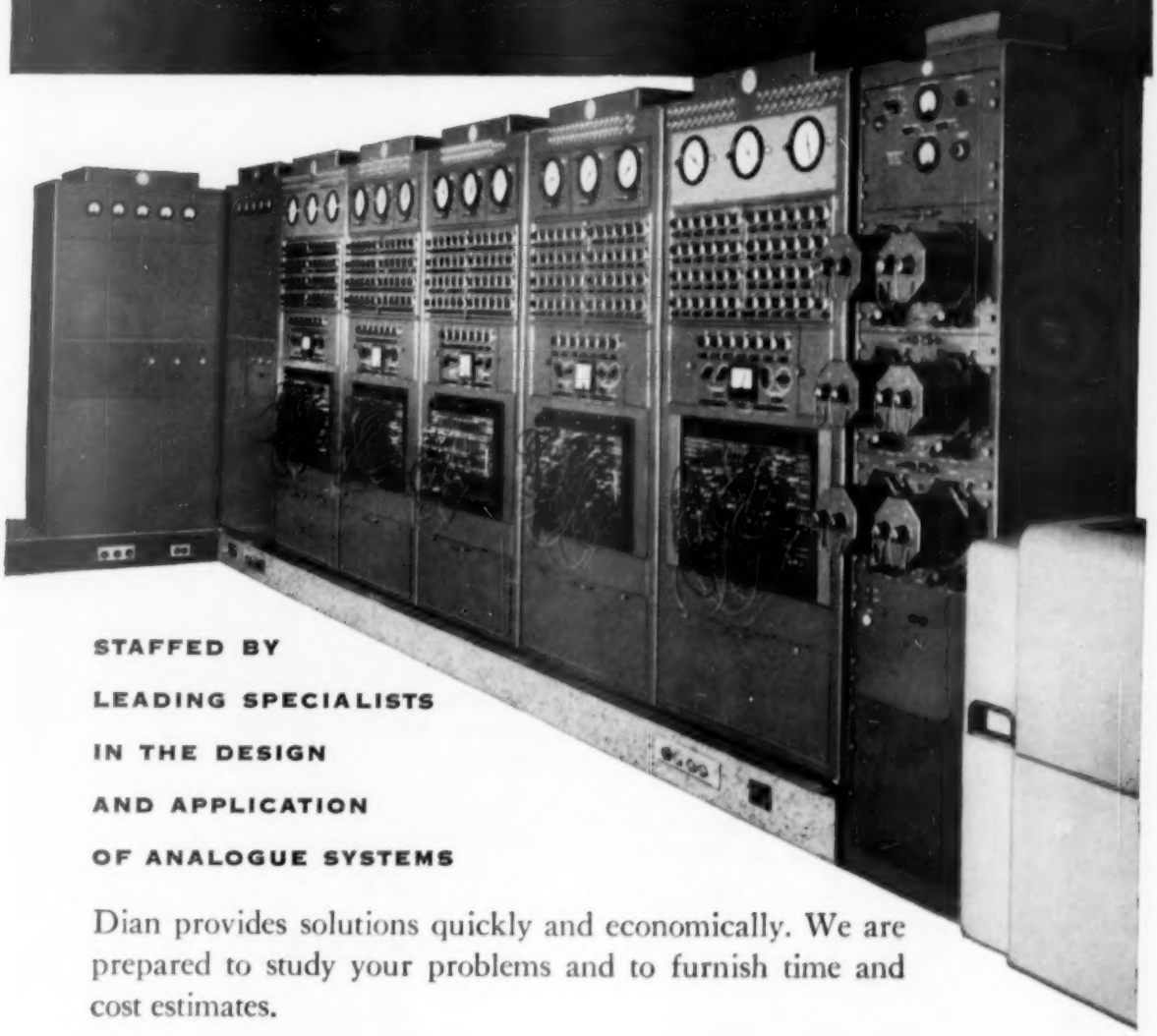
Since 1855—Crane Co., General Offices: Chicago 5, Ill. Branches and Wholesalers Serving All Areas

NOW AVAILABLE

TO GOVERNMENT AND INDUSTRY —

A HIGH ACCURACY • HIGH PRECISION

ANALOGUE COMPUTING SERVICE



STAFFED BY
LEADING SPECIALISTS
IN THE DESIGN
AND APPLICATION
OF ANALOGUE SYSTEMS

Dian provides solutions quickly and economically. We are prepared to study your problems and to furnish time and cost estimates.

DIAN

LABORATORIES, INC.

111 BROADWAY • NEW YORK 12, NEW YORK • REPUBLIC 4-0555

IN CANADA: DATA PROCESSING ASSOCIATES

[illegible] ST. E. • [illegible]

SUPERIOR TUBE COMPANY • NORRISTOWN, PA.

TELEPHONE COLLEGEVILLE 9-7291 • TELETYPE COLLEGEVILLE, PA. 378

Superior Tube
The big name in small tubing

Dear Reader:

If you plan to be at the Trade Fair of the Atomic Industry, Sept. 24-28, Navy Pier, Chicago...

Be sure to visit the Superior exhibit in Booth 440. Our Nuclear Products Division has planned to display specially designed fixtures and equipment which you will find interesting and informative.

When you stop in, be sure to ask for copies of the Superior reports on "Tubing for Atomic Power." There are five in all, covering materials, facilities, services, tolerances, and an introduction to Superior and its activity in the atomic energy field.

Zirconium and zirconium alloys, as well as 37 of the nearly 60 special analyses offered by Superior (in addition, we also offer 63 standard analyses), will be shown.

Also on display will be tubing in a variety of analyses, shapes and sizes. You will be able to see for yourself the smooth, clean OD and ID surfaces, and the overall premium quality of Superior tubing.

If you cannot attend the show, drop us a line, asking for the reports on "Tubing for Atomic Power."

Cordially,

SUPERIOR TUBE COMPANY

SUPERIOR TUBE ANNOUNCES THE OPENING OF ITS NUCLEAR PRODUCTS DIVISION

Our Nuclear Products Division is specially equipped to produce precision products and to perform a variety of operations on materials for nuclear power installations. However, its scope will not be limited to tubular forms. Fabrication of special shapes and components other than tubing will be included, from sheet, bar and plate. This division will work primarily with the reactive metals, titanium, zirconium and their alloys. But it will also fabricate stainless steels, some high-nickel alloys, and rare metals having special nuclear applications.

FACILITIES

- *Special vacuum furnaces for heat treating*
- *Vacuum chamber for inert arc welding of precision parts to extremely close tolerances for subassemblies*
- *Precision machining equipment (largely for milling and turning) accurate to 1/1000 in. in 40 in.*
- *Completely air-conditioned shop*
- *Three hydraulic presses, up to 350 tons, for hot and cold forming sheet and plate*
- *Vapor and alkaline degreasing facilities*
- *Pickling facilities to handle reactive metals*
- *Rinsing facilities, with high purity de-ionized water for washing all pickled parts to be welded and heat treated*
- *Inspection of intricate shapes, using precision gages and testing equipment, and a surface plate, accurate to 25 millionths of an inch*
- *Special dies for straightening sheet, plate, bar and rod*
- *Equipment for corrosion testing under high pressures (up to 3000 psi) and temperatures (up to 750° F.)*

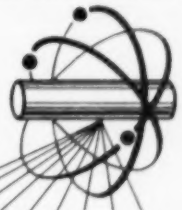
SERVICES

We offer design engineering services in the fabrication of control rod channels, assembly channels, control rods, fixtures, tools and other components required for various types of nuclear reactors, as well as fabrication of subassembly parts, and intricate shapes. We are staffed with mechanical, metallurgical and welding engineers to help you solve your fabrication problems.

We can conduct pilot runs for new fabricated assemblies, and establish production techniques for such items under strict quality control.

Write for more information and your free copy of Bulletin No. 200. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

All analyses .010 in. to ⅞ in. OD—certain analyses in light walls up to 2½ in. OD.



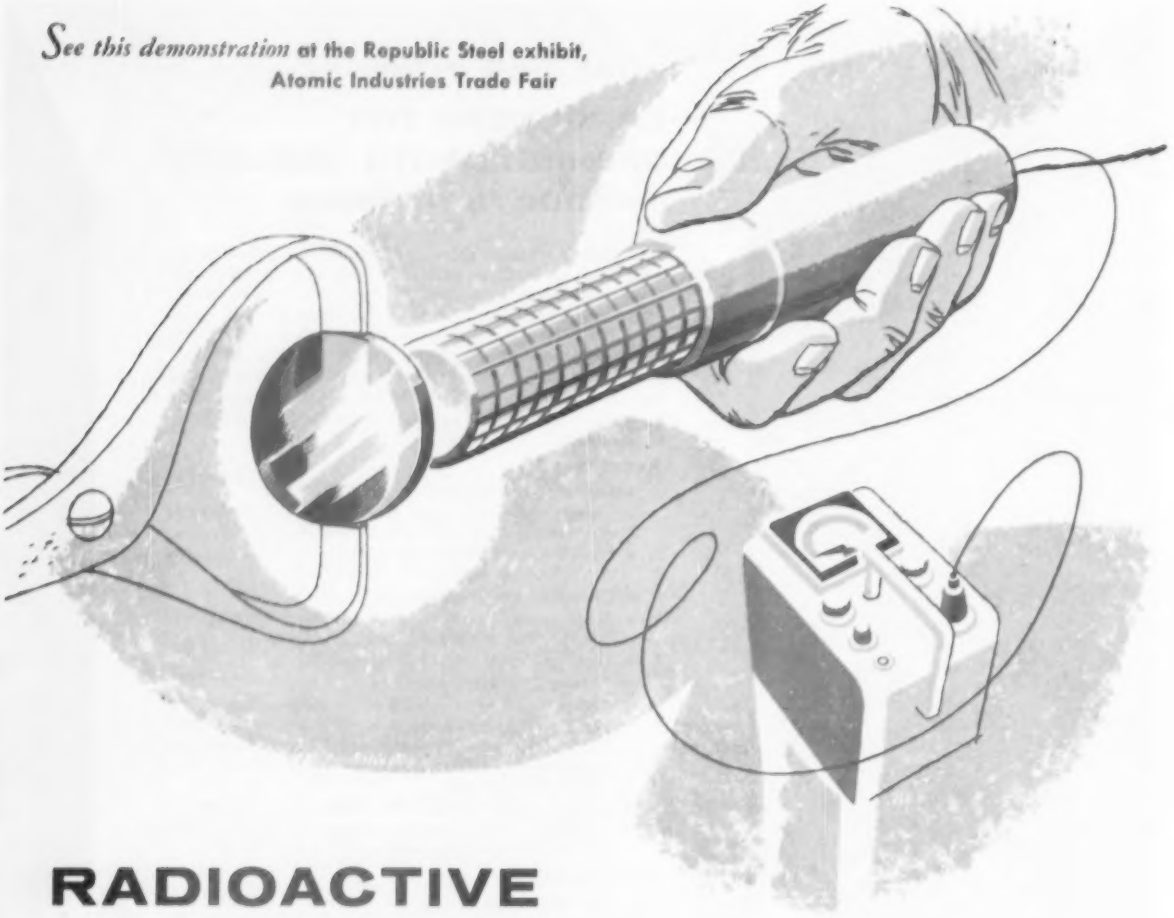
Superior Tube

The big name in small tubing

NORRISTOWN, PA.

West Coast: Pacific Tube Company • 5710 Smithway St., Los Angeles 22, Calif. • RAymond 3-1331

See this demonstration at the Republic Steel exhibit, Atomic Industries Trade Fair



RADIOACTIVE RESIDUES

are no cleaning problem on ENDURO Stainless Steel equipment

Come to the Trade Fair of the Atomic Industries, September 24 to 28 in Chicago, and let us demonstrate to you the ease of decontaminating isotope equipment built of Republic ENDURO® Stainless Steel.

Even the most persistent radioactive materials can be removed from ENDURO Stainless Steel again and again without harm to the metal.

While you are at the Republic booth, you'll also see examples of nuclear equipment manufactured from ENDURO Stainless Steel sheets, tubing, and plate, Republic Titanium, and Republic Alloy Steels. You can also obtain engineering and metallurgical data to help design and build atomic energy equipment from these Republic materials.

If you can't visit us at the Show, write or call the Republic Steel sales office in your city. Or write to Department N-56D.

See us at Booth 220-222

ATOMIC INDUSTRIES TRADE FAIR

Navy Pier, Chicago

SEPTEMBER 24-28

REPUBLIC STEEL

Cleveland 1, Ohio

World's Widest Range of Standard Steels and Steel Products

what's new in nucleonics

. . . from Borg-Warner

"Design it better—make it better" has long been the guiding principle at Borg-Warner. In line with this concept of progress, B-W engineering-production skill and experience are contributing daily to important technological advances in the field of nucleonics. What's new in radiation instruments, manipulators and pump equipment—from Borg-Warner—is described in these pages.

Almost every American benefits every day from the 185 products made by

ENGINEERING B-W PRODUCTION

BORG-WARNER

Another Byron Jackson FIRST in NUCLEAR PUMPS...

BJ Liquid Sodium Pump

WORLD'S LARGEST LIQUID SODIUM PUMP FEATURES MANY DESIGN "FIRSTS"

This new Byron Jackson pump will be used as a primary cooling pump for one of the nation's first full-scale commercial power plants using nuclear fuel.

The pump is approximately 32 feet high with a 6 foot diameter. Rated at 1000 hp, it will pump liquid sodium at a temperature of 1000° F. and deliver 11,800 gpm against a total dynamic head of 310 feet.

Of special interest are Byron Jackson's engineering accomplishments in designing the pump and installation for "packaged" removal. Basically the pump is divided into two sections—(a) suction tank incorporating suction and discharge nozzles which will be permanently welded into the system, and (b) the complete motor and pump assembly which can be pulled as a unit for routine maintenance and inspection with maximum ease, speed and safety. The "packaged" design even provides for shielding (normally separate from the pump assembly) to be integrated within the pump motor support assembly.

This record-making liquid sodium pump with its special design features marks another step in Byron Jackson's continuing leadership in the liquid metal pumping field.

BYRON JACKSON PUMPS
INCORPORATED
A SUBSIDIARY OF BORG-WARNER CORPORATION

ENGINEERING B-W PRODUCTION

P.O. Box 2017A, Terminal Annex • Los Angeles 54, California

See the BJ Nuclear Pump Display
Booth 311 · Trade Fair of the Atomic Industry

DETECTOLAB INSTRUMENTS

for RADIOISOTOPES *in*

HOSPITALS...

Medical Spectrometer • Rate Meters • Scintillation Probes • Scalers • Well Counters • Film Badges • Lead Shields • Portable GM Counters

UNIVERSITIES...

Single Channel Pulse Height Analyzer • Gas Flow Counters • Linear Amplifiers • Spectrometer Scintillation Detectors • Regulated Power Supplies

INDUSTRY...

Radiation Alarm Systems • Scintillation Counters • Pulse Generators • Friction Ware Instruments • Chemical Process Control Instruments • Geiger Counters

A. E. C. LABORATORIES...

Multi-channel Analyzers • Recording Gamma Ray Spectrometers • Reactor Control Instruments • Coincidence Circuits • Alpha Survey Meters • Neutron Counters

DETECTOLAB, INC., an affiliate of Borg-Warner Corporation, is supplying industrial, scientific and research laboratories in Europe, Asia, and America with latest nuclear instruments, built with the best known electronic components, designed on the Building Block principle, so scientists may have the proper tools for faster scientific advancement. Write today to DETECTOLAB, INC., 6542 N. Sheridan Road, Chicago 26, Illinois for information on the RADIOISOTOPE INSTRUMENTS.

DETECTOLAB SALES OFFICES

PHOENIX, ARIZONA
Bernstein & Company
39 West Adams

PASADENA, CALIFORNIA
McCarthy Associates
16 North Marengo Ave.
Room 604

DENVER 3, COLORADO
Scientific Instrument Co.
1450 Pennsylvania Street

CORAL GABLES, FLORIDA
Kimball Electronics
209 Alhambra Circle

ATLANTA, GEORGIA
Stanley K. Wallace Assoc., Inc.
1808 Willis Mills Road, S. W.

WICHITA, KANSAS
Kemco, Incorporated
6427 E. Kellogg Street

LOUISVILLE, KENTUCKY
B. Preiser Company, Inc.
108 W. Market Street

BALTIMORE 18, MARYLAND
Thomas L. Taylor Eng. & Sales Col.
2100 St. Paul Street

FERNDALE 20, MICHIGAN
Electro-Mec Associates
109 E. Nine Mile Road

ST. PAUL 4, MINNESOTA
Northport Engineering, Inc.
186 N. Fairview Avenue

FAYETTEVILLE, N. Y.
W. M. Hannah
305 Redfield Avenue

CLEVELAND 13, OHIO
Lowry-Dietrich Company
316 Marion Bldg.

PENN VALLEY, NARBERTH, PENNSYLVANIA
A. Bruce Edwards
1118 Woodbine Avenue

PITTSBURGH 4, PENNSYLVANIA
Lowry-Dietrich Company
1404 Swantek Street

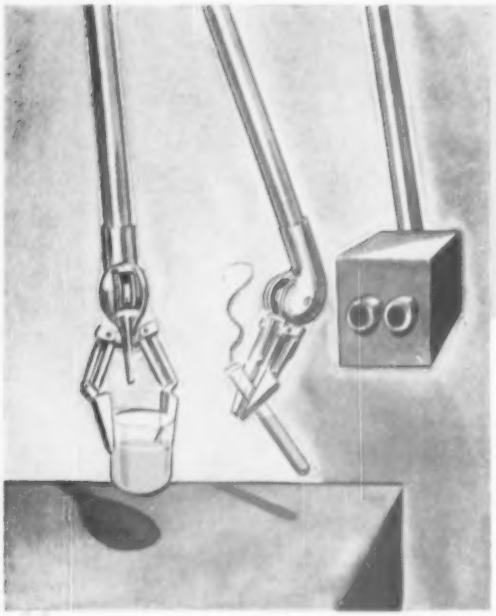
SEATTLE 55, WASHINGTON
Applied Radionics Corp.
14305 — 20th Avenue

AJAX, ONTARIO, CANADA
Bayly Engineering, Ltd.
First Street

WINNIPEG 9, MANITOBA, CANADA
Nuclear Enterprises, Ltd.
1750 Pembina Highway

EXPORT SALES: BORG-WARNER INTERNATIONAL CORP., 36 South Wabash Avenue, Chicago 3, Ill.—Cable Address: BORINTCO

detectolab, INC. *affiliate of* **BORG-WARNER**



NOW AVAILABLE

Electro-Mechanical

MASTER-SLAVE

Manipulator

The Marvel-Schebler Products Division of Borg-Warner Corporation now offers fully remote master-slave handling. The advanced electro-mechanical manipulator developed from Argonne National Laboratory designs by engineers of the Borg-Warner Research Center extends the advantages of master-slave handling to new areas and provides opportunity for greater flexibility in cave design. Reduced headroom requirements, increased volume coverage, and the elimination of wall penetrations provide attractive economies in cave construction. With compatable stereo television, the flexibility and remote features of this manipulator open new fields of application. Please write for our descriptive brochure.

ENGINEERING BW PRODUCTION

BORG-WARNER CORPORATION

MFG. BY MARVEL-SCHEBLER *Products Division*

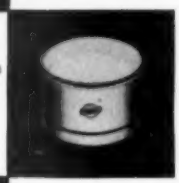
DECATUR, ILLINOIS

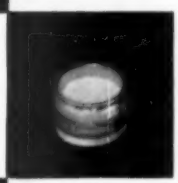
SEE AND OPERATE THE MANIPULATOR — WE'LL BE AT THE ATOMIC TRADE FAIR IN CHICAGO, SEPT. 24 - 28

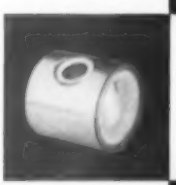
Harshaw

SODIUM IODIDE (Thallium) SCINTILLATION CRYSTALS

for Gamma Radiation Detection Instruments







"Harshaw Quality". . . inherent in each Harshaw-made crystal

The high purity, clarity, and proper activation of Harshaw Crystals are a natural result of our long pioneering experience in the delicate art of crystal growing.

Harshaw Purity means light absorbing impurities are reduced to infinitesimal traces.

Harshaw Clarity gives highest possible transmission of the crystal's own emitted light.

Harshaw Activation means the optimum thallium concentration ensuring maximum energy conversion.

Our crystals are normally supplied hermetically sealed in aluminum containers engineered to secure maximum light collection. We will custom design these units to fit your specific requirements. Harshaw crystals are currently used in nuclear physics research, well logging, uranium prospecting, medical research, and industrial process and product control.

No need to specify "Harshaw Quality". . . you get it automatically when you order Harshaw Crystals. We encourage requests for technical assistance. Prices, specifications, or other information will be sent in answer to your inquiry.

OTHER HARSHAW SCINTILLATION CRYSTALS AVAILABLE IN THE FOLLOWING FORMS:

Potassium Iodide (Tl) • Cesium Iodide (Tl) • Cesium Bromide (Tl)
Anthracene • Stilbene • Naphthalene
Lithium Iodide (Eu) for neutron detection • Sodium Iodide (rough cut blanks)

HARSHAW

THE HARSHAW CHEMICAL CO.

1945 EAST 97TH STREET • CLEVELAND 6, OHIO

THIS

Mettler PRECISION BALANCE

+

THE NEW TARING DEVICE

=

GREATEST EASE, SPEED AND PRECISION!

12 TO 20 WEIGHINGS PER MINUTE

TYPE NO.	CAPACITY	PRECISION	TARING RANGE
K-4	4000 g	± 0.3 g	500 g
K-5	2000 g	± 0.2 g	500 g
K-7	800 g	± 0.03 g	100 g

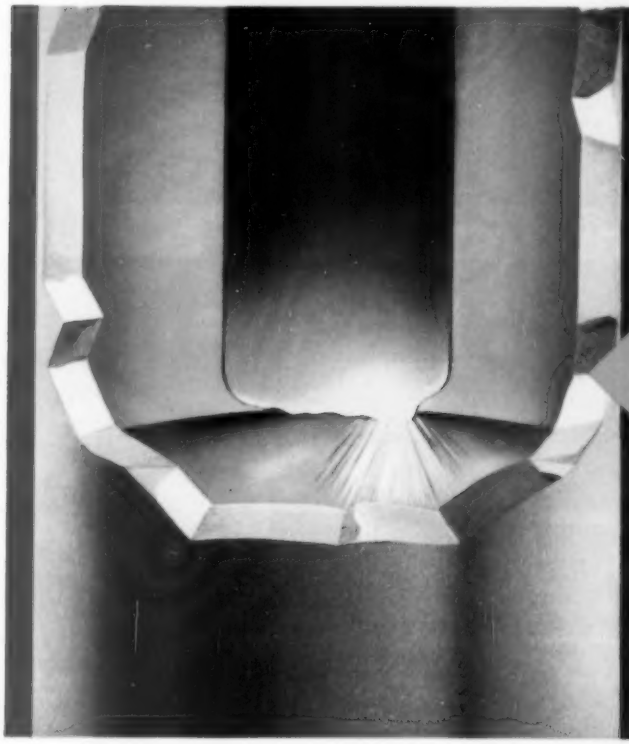
Write us today for our new booklet describing the precision balances. Ask us to arrange for a demonstration in your laboratory.

Mettler

INSTRUMENT CORPORATION

BOX 242, HIGHTSTOWN, N. J.

NRC VACUUM CONSUMABLE ELECTRODE ARC FURNACES



In NRC Arc Furnaces
We Have Melted . . .

W
Ta
Mo
Nb
Hf
Zr
Th
Ti
Co
Ni
U

Designed by Engineers Who OPERATE Them!

With an NRC Vacuum Arc Furnace you can now melt — economically and reliably — refractory and reactive metals and alloys. Because each of these metals behaves differently, satisfactory design of vacuum arc furnaces is unusually dependent upon operating experience. Built into your NRC Vacuum Arc Furnace are features which result from the intimate familiarity gained from building and operating such units for more than a decade. For instance, the extra-safe NRC mold design reduces the danger of mold burn-through.

If you are considering the purchase of a vacuum arc furnace — laboratory, pilot plant, or production size — we would like to point out the design features of an NRC furnace which will assure you dependable, efficient, and safe operation. For further information write NRC Equipment Corp., a subsidiary of National Research Corp., Dept. 89, Charlemont St., Newton Highlands 61, Mass.

Visit our Booth No. 308 — Atomic Trade Fair — Chicago, Sept. 24-28

NRC

NATIONAL RESEARCH CORPORATION
Serving the ATOMIC INDUSTRY through:

NRC METALS CORP. — Zirconium and Thorium

NRC EQUIPMENT CORP. — Industrial and Laboratory High Vacuum Equipment

NRC RESEARCH DIV. — Research in coatings, liquid metals, fuel reprocessing

VACUUM METALS CORP. — Jointly owned with Crucible Steel Corp. of America — cast alloys, experimental melting and fabrication, nuclear alloy development

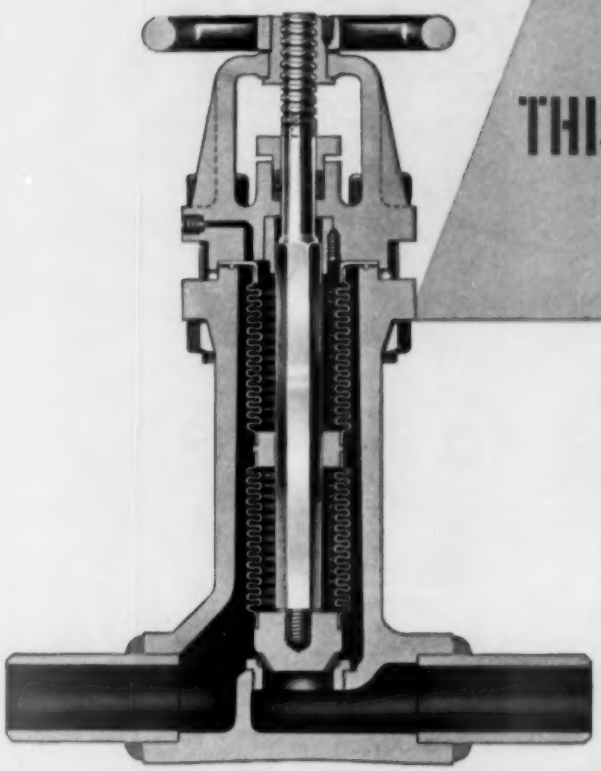
Private Industry Progress...

Shown above are views of our new and expanded fuel element fabrication facility. Privately owned and equipped, this facility marks the third expansion of our fuel element operations in four years — and additional capacity is currently underway.

With our increasing experience in the production of fuel elements, we are confident we can meet the challenges of both industrial and governmental nuclear reactor programs.

Let us assist in your reactor program by supplying information on fuel element fabrication based upon your specifications and design! Send for free brochure on Fuel Element Fabrication today.

METALS & CONTROLS CORPORATION
NUCLEAR PRODUCTS DIVISION
1309 FOREST STREET, ATTLEBORO, MASS.



WHAT MAKES THIS PACKLESS VALVE LEAK-PROOF?

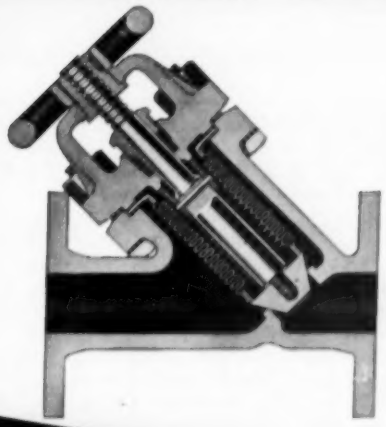
Even at pressures of 500 psi and temperatures of 1000°F., Sylphon Packless Valves prevent corrosive or flammable fluids from leaking and creating hazards.

How? Simply by using a bellows seal around the valve stem . . . not an ordinary bellows, but a SPECIAL SYLPHON BELLOWS that gives added protection and safety. Here are some of its outstanding features:

- No weak seams to open and leak.
- Cold-worked and hydraulically formed for resiliency and long life.
- Extra thick sidewalls . . . 2 or more plies of metal for extra strength.

In Sylphon Packless Valves you get double protection . . . the bellows seal *plus* regular packing which functions only in an emergency.

There's a wide selection of sizes and types. Sylphon Packless Valves are available in brass, bronze, cast iron or stainless steel. Special types are available for specific applications in the chemical and atomic industries. For complete information, return the coupon below.



Robertshaw-Fulton
CONTROLS COMPANY
FULTON SYLPHON DIVISION

Robertshaw Fulton Controls Co.
FULTON SYLPHON DIVISION
Knoxville 1, Tennessee

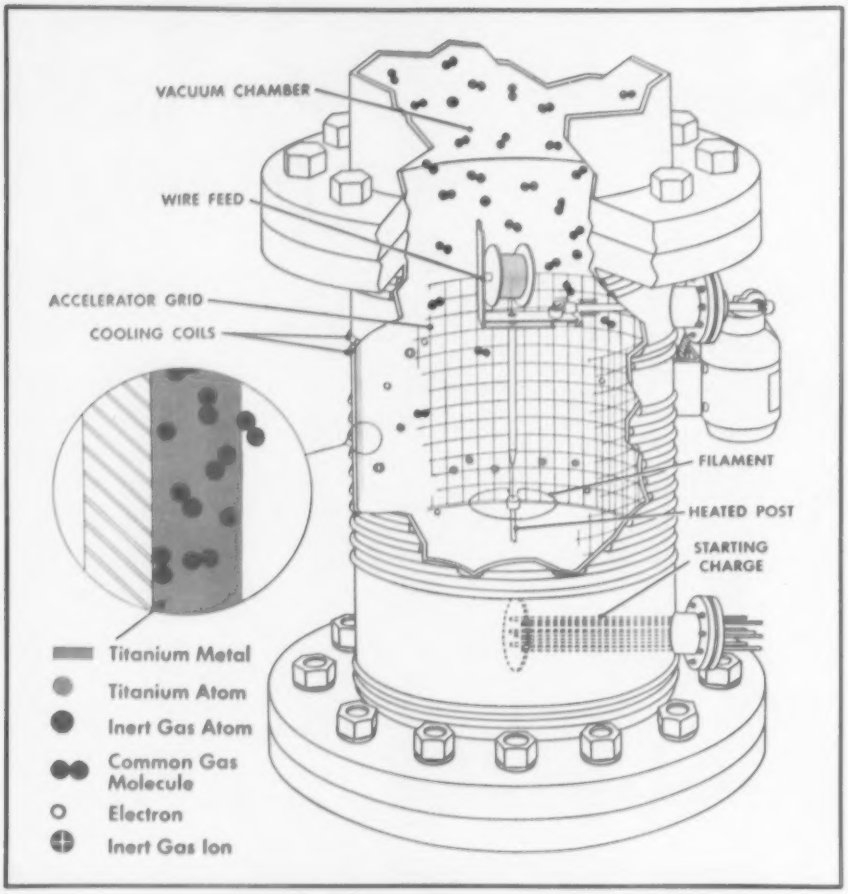
Send Bulletin RV-813 describing all Sylphon Packless Valves.

Name_____

Company_____

Address_____

City_____ State_____



A **dry** high vacuum **electronically**

With this new electronic vacuum pump —the Evapor-Ion—you can now produce a vacuum of 10^{-4} to 10^{-9} mm Hg completely free of contaminating vapors.

How the Evapor-Ion pump works

Pure titanium wire is fed onto a post heated by electron bombardment from the filament. The titanium evaporates and, upon striking the cooled pump wall, condenses as a thin layer.

Gas molecules wander into the pump from the vacuum chamber. Molecules of the active gases, which comprise over 99% of the air, move aimlessly about. Eventually they strike the titanium layer where they are held as compounds. As each layer of titanium becomes chemically saturated, a fresh layer of metal is deposited.

The inert gases do not combine chemically with the titanium. Some of the electrons emitted by the filament collide with and ionize the inert gas molecules. The electrical field of the accelerator grid violently repulses these positive ions and drives them into the titanium layer. Here they are buried by subsequent titanium evaporation.

This constant removal of air molecules by evaporation and ionization constitutes a pumping action. Nitrogen is pumped at speeds as high as 2000 liters per second.

Applications for the Evapor-Ion

The Evapor-Ion is ideal for noncyclic vacuum systems such as betatrons, synchrotrons and other particle accelerators. In addition it has potential applications in the fields of metallurgy, electronics and metallizing.

For further information on this unique pump, write to the Rochester Division for Bulletin 6-140-Z4.

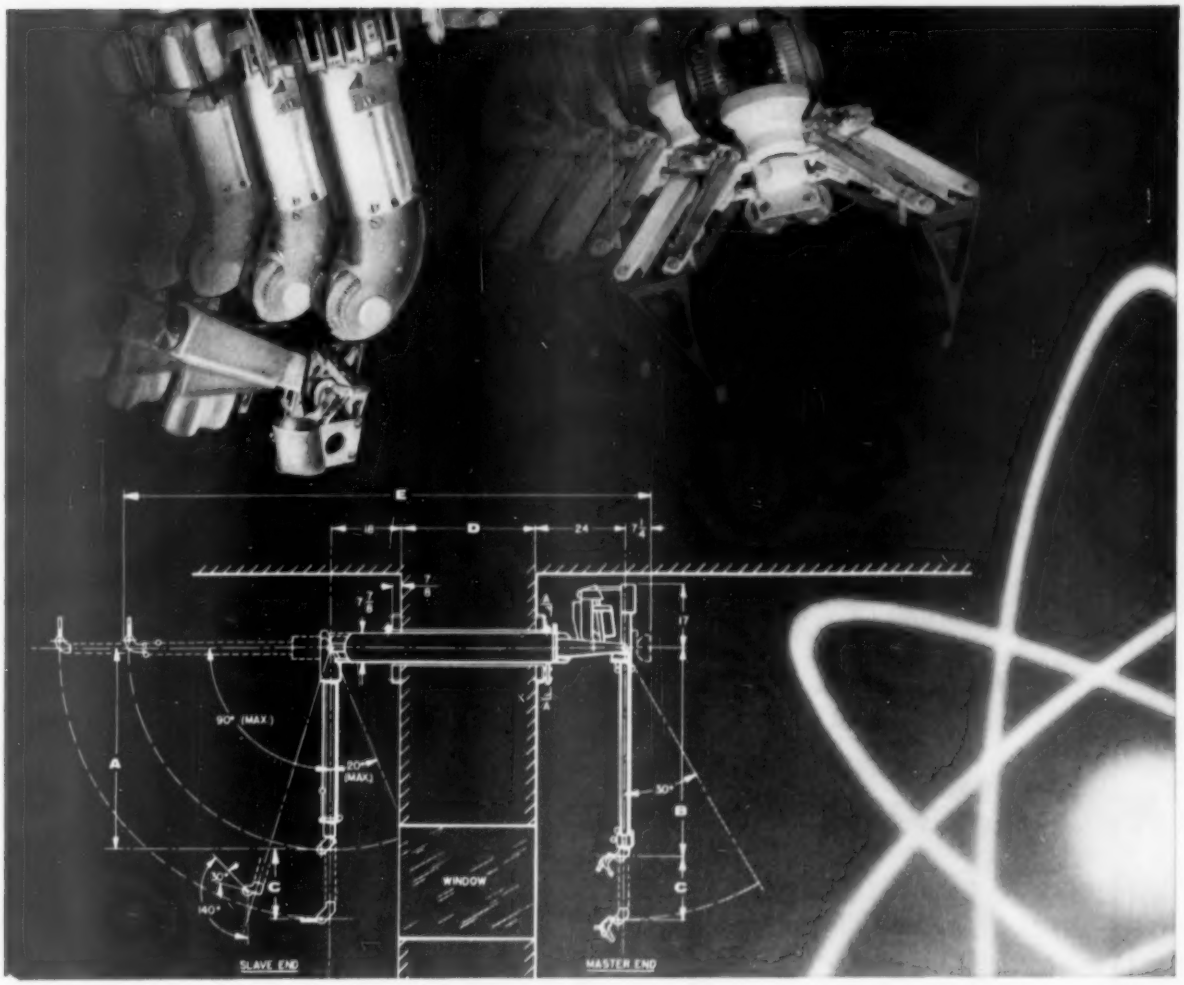
Consolidated Electrodynamics

CORPORATION

Rochester Division, Rochester 3, N. Y.

formerly Consolidated Vacuum

Sales Offices: Albuquerque • Atlanta • Boston • Buffalo • Chicago • Dallas • Detroit • New York • Pasadena • Philadelphia • San Francisco • Seattle • Washington, D. C.



AMF MANIPULATORS

produced in quantity for quality and low cost

AMF ATOMICS — the nation's leading designer and producer of radio-active materials handling equipment—produces a complete line of Model 8 Master-Slave Manipulators, uniformly fashioned to the highest possible precision standards.

Quantity production made possible by the large demand for AMF Manipulators assures uniform quality and parts interchangeability difficult to achieve on a "custom made" basis. And the *variety* of interchangeable parts produced allows assembly to *individual* needs. (See chart.)

Unexcelled for dexterity and all-around reliability, the AMF Manipulator, Argonne Model 8, can be equipped with a variety of special-purpose slave ends to perform the most specialized of hot cell operations. It has an extremely delicate touch, yet can handle weights up to 30 lbs. and more. And it can be easily transferred from one thru-wall position to another, to provide maximum usefulness.

For manipulators, or radio-active materials handling equipment of any kind, get in touch with AMF ATOMICS today.

Immediate Delivery—All Models With Right or Left Hand Grip

Model Number	A	B	C	D
3666	52¼	55¼	36	24
3672	52¼	55¼	36	30
3678	52¼	55¼	36	36
3684	52¼	55¼	36	42
3688	52¼	55¼	36	46
3690	52¼	55¼	36	48
3966	55¼	58¼	39	24
3972	55¼	58¼	39	30
3978	55¼	58¼	39	36
3984	55¼	58¼	39	42
3988	55¼	58¼	39	46
3990	55¼	58¼	39	48

• Radiation Process Equipment • Power and Research Reactors • Reactor Control Systems • Radio-active Materials Handling Equipment

Be sure to see the
AMF ATOMICS EXHIBIT
Booth 407-9
ATOMIC FAIR
Navy Pier · Chicago · Sept. 24-28

AMF ATOMICS

AMF ATOMICS Inc.
AMF Building • 261 Madison Ave. • New York 16, N. Y.
Subsidiary of AMERICAN MACHINE & FOUNDRY COMPANY

FOR PERSONNEL PROTECTION

ARCHER LEAD GLASS GOWN

This garment of spun lead glass fabric is designed to protect vulnerable parts of the body from radiation. Measurements made at 75 K.V. and 0.5 Aluminum gave the following results:

	% transmission
1 layer	15
2 layer	6
3 layer	4

1. Made in gowns and aprons. Also available in sleeves and yard goods.
2. Ideal for patient protection.
3. Made in aprons 12 x 12, 12 x 18, 18 x 24, 18 x 43 or in intermediate sizes.

REFERENCES:

1. Archer, V. W., *et al.* Protection against x-ray and beta radiation; lead glass fabric. *J.A.M.A.*, 1952, 148, 106-108.
2. Archer, V. W., *et al.* Protection of personnel during roentgenological examinations. *Am J. Roentgenology & Rad. Therapy*, 1955, 667-673.
3. Dubilier, Jr., Wm., *et al.* Radiation hazard during angiocardiography. *Am J. Roentgenology & Rad. Therapy*, 1953, 441-444.

MEMORIAL MODEL "CORAY" CO^{60} IRRADIATOR

Engineered by BAR-RAY with U.S. ATOMIC ENERGY COMMISSION

1. LARGE FIELDS:
   28 x 28 cm. at 50 cm.
   40 x 40 cm. at 70 cm.
2. Diaphragms to pin-point fields.
3. Designed for standard AEC capsule; will accommodate Cesium.
4. Meets all safety requirements of National Bureau of Standards new Handbook 54 and Atomic Energy Commission.
5. Remote automatic operation.
6. Floor or ceiling mounted.
7. Economically priced — $12,000.

A complete range of Cobalt^{60} irradiators for therapy, industry and research are available in six basic models from 250 to 1,000 curies.

CORNING RADIATION SHIELDING GLASS

Bar-Ray is distributor for this 3.3 density, non-browning and 6.3 density lead glass. The 3.3 glass will not discolor when exposed to high level radiation. It has mechanical strength comparable to commercial sheet glasses and excellent chemical stability. A variety of sizes are available in thicknesses of 2" 3", 4", 6" and 8".

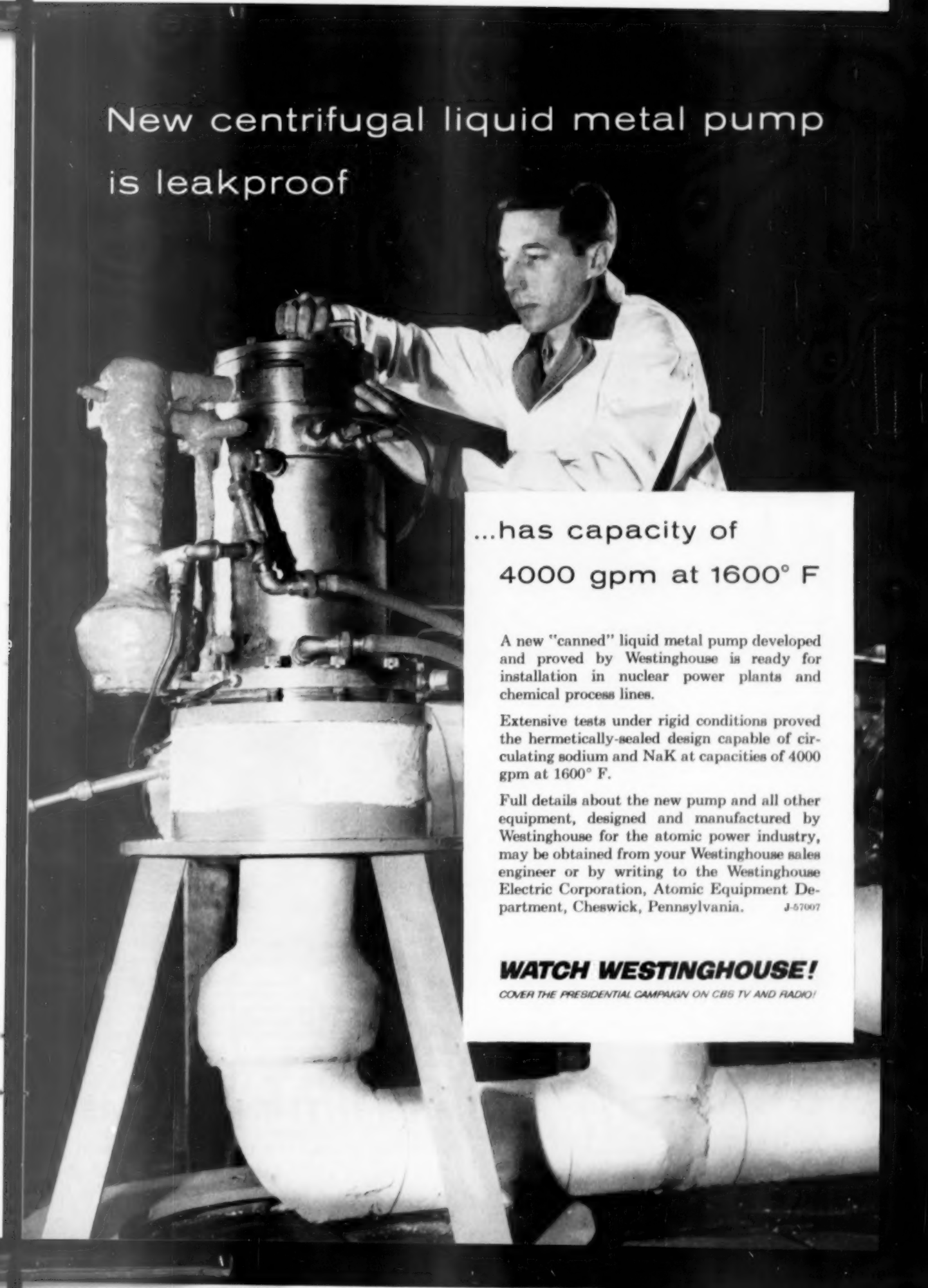
SOLD THROUGH YOUR DEALER *You are most cordially invited to visit our plant* **WRITE FOR LATEST CATALOG**

BAR-RAY PRODUCTS, INC.

219 — 25th STREET, BROOKLYN 32, N.Y. • **Telephone: SOuth 8-1020**

European Representative: Mr. C. E. Ferrero, Via G. Tomassetti, 8, Rome, Italy

Stainless Steel Processing Systems • Isotope Fume Hoods and Labs • Film Transfer Cabinets • Thermostatic Valve Assemblies
Lead Lined Chests and Safes • Archer Lead Glass Gowns • Lead Protective Screens • Lead Insulated Hoods


New centrifugal liquid metal pump
is leakproof
...has capacity of
4000 gpm at 1600° F
A new "canned" liquid metal pump developed and proved by Westinghouse is ready for installation in nuclear power plants and chemical process lines.
Extensive tests under rigid conditions proved the hermetically-sealed design capable of circulating sodium and NaK at capacities of 4000 gpm at 1600° F.
Full details about the new pump and all other equipment, designed and manufactured by Westinghouse for the atomic power industry, may be obtained from your Westinghouse sales engineer or by writing to the Westinghouse Electric Corporation, Atomic Equipment Department, Cheswick, Pennsylvania.
J-57007
WATCH WESTINGHOUSE!
COVER THE PRESIDENTIAL CAMPAIGN ON CBS TV AND RADIO!

NUCLEAR NEWS FROM ATOMICS INTERNATIONAL

Nuclear reactors now being built for science and industry—for power and radiation

Within a single decade ATOMICS INTERNATIONAL engineers and scientists have developed a broad range of experience in the nuclear field through the design, construction and operation of a wide variety of reactors. This work includes four reactors completed and now in operation; four more reactors now in construction; and seven major engineering design projects completed.

Sodium Reactor Experiment nears completion in Santa Susana Mountains. It is being built and will be operated by Atomics International as a key part of AEC's nuclear power development program.

ATOMICS INTERNATIONAL, a division of North American Aviation, Inc., is a leader in the development of advanced reactor technology. A new power reactor concept, the Organic Moderated Reactor Experiment, is scheduled to be built by ATOMICS INTERNATIONAL for the Atomic Energy Commission at the National Reactor Testing Station in Idaho. This promising experiment will use an organic material—a carbon-hydrogen compound—in the dual role of moderator and coolant.

The diversified nuclear program at ATOMICS INTERNATIONAL includes:

1. Sodium Reactor Experiment. Located in Santa Susana Mountains, near Los Angeles. Fuel: either slightly enriched Uranium, or Thorium and U-233. Output: 20 Thermal Mw. Though experimental, the reactor will be equipped with heat exchanger and turbogenerator by Southern California Edison, who will feed 6.5 Mw of electric power to the surrounding area.

2. Full-scale Sodium Graphite Reactor Design. Fuel: same as above. Heat output: in the order of 250 Thermal Mw. Power Output: Uranium—75 Mw; Thorium—100 Mw; Thorium (after further development)—125 Mw. Capital costs, with full generating equipment, around $300 per Kw with Uranium, expected to be reduced with Thorium eventually to $200 per Kw. Power costs would thus decrease from 11.1 mills/kwh to 6.5 mills/kwh.

3. Water Boiler Research Reactor. Designed and built by ATOMICS INTERNATIONAL for use on Atomic Energy Commission research projects. Fuel: enriched Uranium. Power 5 watts. Flux: 10^{9}n/cm^2/sec (thermal). Experimental facilities include exposure holes, through-tube and vertical thermal column.

4. Livermore Research Reactor. For Atomic Energy Commission's laboratories at Livermore, Calif. A higher power version of the Water Boiler Research Reactor designed to operate at 500 W. These were the first two reactors in California.

5. Medical Research Reactor. Designed for a southern California university. Fuel: Uranyl sulphate, highly enriched with U-235. Power: 50 kilowatts. Thermal neutron Flux: 1.7 x 10^{12}cm^2/sec. Provision for gamma intensities to 1.3 reb/min per kw, fast neutron intensities of 4 reb/min per kw; also utilization of pure gamma activity of fission gases. Excellent exposure facilities for patient therapy and biological research. First reactor specifically designed for medical use.

6. Industrial Research Reactor for Armour Research Foundation of Illinois Institute of Technology, Chicago. Similar to 5 above, with experimental facilities for industrial applications. This reactor is now operating on a planned schedule that includes "time" for participating companies. This is the first reactor designed specifically for private industrial research.

7. General Research Reactor for Atomic Energy Research Institute, Japan. Similar to the Armour and Medical Research reactors described above. This will be the first nuclear reactor in the Far East, and is slated to be completed in 1957.

ATOMICS INTERNATIONAL has complete designs for reactors with a variety of fuel moderator and cooling systems for various applications, and offers a complete program of services in connection with all reactor projects, including:

- Advice on most suitable reactor type for a specific use
- Assistance in reactor site selection
- Aid in meeting AEC requirements
- Coordination of reactor plans with building plans
- Installation supervision
- Training of operating and maintenance personnel
- Assistance in fuel loading and initial reactor operation
- Design counsel in later modification or expansion
- Assistance in public information

Dr. Marlin Remley of Atomics International activates Armour Reactor—first for private industry.

If you are interested in any phase of our activities, ATOMICS INTERNATIONAL is staffed and equipped to help you. Please write: Director of Technical Sales, Dept. N-N5, ATOMICS INTERNATIONAL, P. O. Box 309, Canoga Park, California. Cable address: ATOMICS.

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.
PIONEERS IN THE CREATIVE USE OF THE ATOM

chemical pumps...

pressures to 50,000 psi • capacities to 15,000 gph

• Built for heavy service. Special non-clogging, abrasion-resistant, vertical valves. Manual or automatic control of capacity. Up to 30 percent saving in horsepower requirement.

PHILADELPHIA PUMPS

PHILADELPHIA PUMP & MACHINERY CO. / 1513 Race St., Phila., Pa. / Subsidiary of American Meter Co.

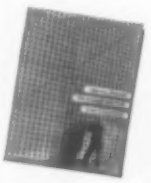
This efficient functional L&N console-cubicle combination will soon be controlling the University of Michigan's Ford Nuclear Reactor (FNR). Shortly after the L&N project engineer made the pre-shipment tests (above), the entire package was shipped to the FNR site.

ANOTHER COMPLETE REACTOR CONTROL, "SYSTEMS ENGINEERED" BY LEEDS & NORTHRUP

• Here's another example of L&N's "complete systems" approach to reactor operation —the control for University of Michigan's 1000-kw Ford Nuclear Reactor. This FNR control includes period, log N, LCR, linear level, and safety channels —all appropriately instrumented. Other Speedomax® recorders measure conductivity in the pool, measure miscellaneous system temperatures, and monitor for area radioactivity. A Speedomax pneumatic controller regulates the temperature of the exit water from the heat exchanger.

Physically, this FNR set-up embodies a variety of integrated, standard instruments. But more broadly, it encompasses the intangibles like engineering consultation, design services, and coordinated planning vital to effective nuclear reactor control.

Write for our brochure, "Control Systems for Nuclear Reactors." Leeds & Northrup Company, 4936 Stenton Ave., Phila. 44, Pa.



LEEDS & NORTHRUP

instruments — *automatic controls* • *furnaces*

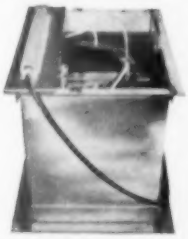
Jrl Ad ND46-70-700(6)

ACOUSTICA ASSOCIATES, INC.

ULTRASONIC NEWS

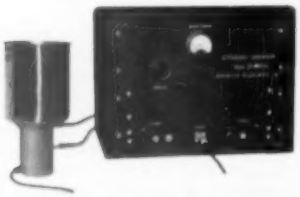
COMPLETE DECONTAMINATION IN MINUTES

- low cost ultrasonic generators and transducers
- rugged, durable equipment
- equipment adaptable to largest production requirements
- reclaims expensive tools, apparatus, manipulators of any shape or dimension

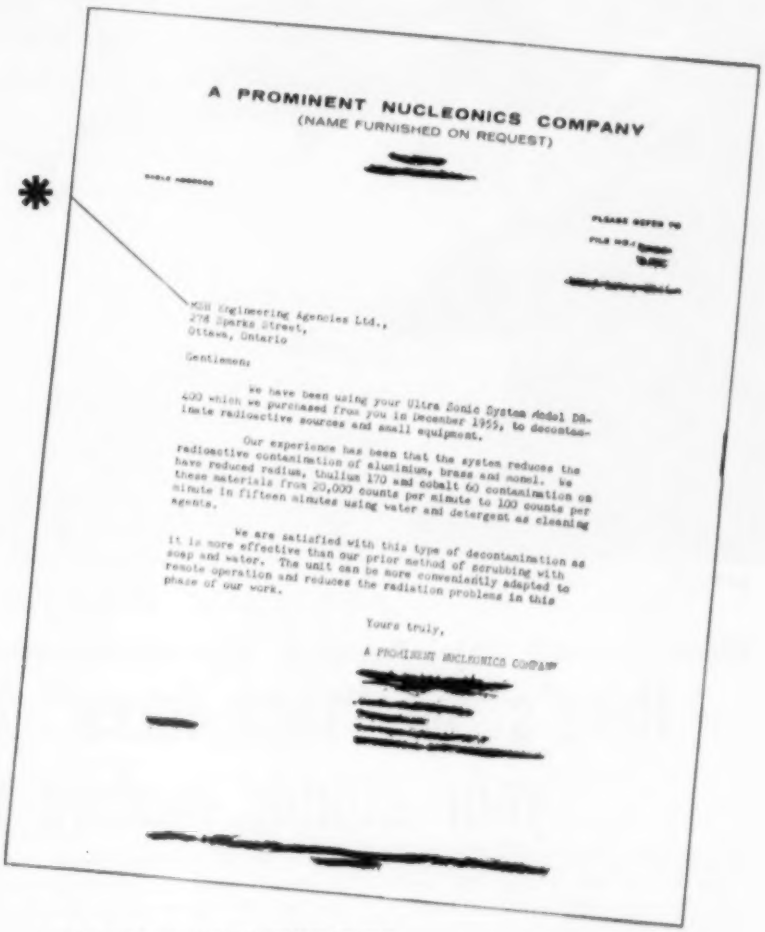


• a section in erection of the world's largest ultrasonic cleaning installation (20 KW), employing DR-2000A electronic generators and barium titanate transducers for radioactive decontamination of parts up to six feet long.

• the first truly portable, heavy duty (2000 W) ultrasonic parts cleaner; multiple array of magnetostriction type transducers, tank, filter, pump-all mounted in mobile console.



• the famous DR-400A Ultrasonic System; an electronic generator furnishing 400 watts to a virtually indestructible magnetostriction type transducer—now in use by leading manufacturers in electronic, metal working, and chemical process industries.



A PROMINENT NUCLEONICS COMPANY
(NAME FURNISHED ON REQUEST)

[redacted]

[redacted]

[redacted]

[redacted] Engineering Agencies Ltd.,
274 Sparks Street,
Ottawa, Ontario

Gentlemen:

We have been using your Ultra Sonic System Model DR-400 which we purchased from you in December 1955, to decontaminate radioactive sources and small equipment.

Our experience has been that the system reduces the radioactive contamination of aluminium, brass and monel. We have reduced radium, thulium 170 and cobalt 60 contamination on these materials from 20,000 counts per minute to 100 counts per minute in fifteen minutes using water and detergent as cleaning agents.

We are satisfied with this type of decontamination as it is more effective than our prior method of scrubbing with soap and water. The unit can be more conveniently adapted to remote operation and reduces the radiation problems in this phase of our work.

Yours truly,

A PROMINENT NUCLEONICS COMPANY

[redacted]

[redacted]

[redacted]

* ACOUSTICA'S CANADIAN REPRESENTATIVE

While at the TRADE FAIR OF THE ATOMIC INDUSTRY . . . see Ultrasonics at work. Acoustica's Chicago representative will be pleased to serve you. For a demonstration visit: CAPPELS-RHODES & ASSOCIATES, INC., 214 West Madison Street, Chicago 7, Ill., Taylor 9-1818

ACOUSTICA ASSOCIATES, INC. •

GLENWOOD LANDING, L.I., N.Y.
GLen Cove 4-5170

KEY MEN at General Electric, such as W. D. Lee, H. C. Ward, Jr., F. J. McGuire, M. E. Petersen and R. H. Adams, show design of first practical large-size electromagnetic pump, at West Milton, N. Y. test site, operated by General Electric for the A.E.C.

Need Canned Motor Pumps? Electromagnetic Pumps?

Here's the "task force" that can plan your atomic motors today...

This same experienced atomic motor "task force" will attend the week-long Atomic Industrial Forum in Chicago later this month. See them there . . . or write today.

An electromagnetic pump (diagram shown in photo) like the one at West Milton is termed the "heart" of the atomic submarine ***Seawolf's*** liquid sodium reactor. This highly important EM pump was designed and manufactured by General Electric's Medium Induction Motor Department in Schenectady, N. Y. Engineers and technicians in this department have produced more large EM pumps for nuclear applications than any other company in the free world. They are equally well known in the industry for their design and manufacturing skill on canned motor pumps for pressurized water reactors. So much so that the department is producing canned motor pumps for nearly every major government nuclear project plus several important commercial power applications.

The Medium Induction Motor Department is participating again this year in the Atomic Industrial Forum to be held in Chicago, September 24–28. The department's display will center around the development of EM and Canned Motor Pumps. The booth will be an integral part of the large General Electric exhibit. 873-3

If you are planning a career in nuclear engineering or atomic motor design, you'll find unlimited opportunity and the most modern facilities at General Electric. For complete information, contact a G-E Medium Induction Motor Department representative at the Palmer House, Chicago, September 24–28. If you are not attending the Forum, send a resume of your training and experience to C. F. Stowell, Medium Induction Motor Dept., General Electric Company, 1 River Road, Schenectady, N. Y.

Progress Is Our Most Important Product

GENERAL ELECTRIC

NUCLEONICS SEPTEMBER, 1956

Jerome D. Luntz, *Editor*

A Mandate

THERE has been mounting evidence in recent months that considerable confusion exists as to where the U. S. stands in the world race to achieve leadership in peacetime atomic energy. Despite the fact that there is no common understanding as to how this race should be judged, there is a certain amount of clamor that we are losing the race. Various statistics are cited to show that we are behind the British or behind the Russians or just behind in general.

Although there is plenty of evidence to refute this—our output at the Geneva conference, if nothing else, was sufficient disclaimer—it now seems important that these viewpoints be recognized for what they mean. This is that one important part of our atoms-for-peace program is failing—the establishment of the U. S. as the world leader in peacetime atomic energy.

In these days when the peacetime atom is so important in international relations, although we may be satisfied ourselves that we're doing the kind of job that should be done, its impact is lost unless others know this also. Thus, we have an obligation not only to see that we *are* the unquestioned world leader but also that we are *recognized* as such.

HOW can we do this? For one thing, we've got to translate our effort into publicly recognizable terms. We've got to make certain that what we're now doing is understood. More important, we ourselves have got to appreciate the criteria that many use to judge performance. One meaningful and irrefutable criterion is delivery of the goods—turning flywheels with nuclear energy.

For example, it's apparent that the ambitious, daring "White Paper" program that the United Kingdom announced last year has captured the imagination of the world. Next month, the British will be dedicating Calder Hall [our heartiest congratulations go to them] and will be on their way to having a mammoth network of central-station nuclear power plants.

But the U. S. program, on the other hand, as sound and as wisely planned as it is, is not arousing the excitement expected, except perhaps among knowledgeable technical people. Best evidences of this are the Congressional interest on the Gore bill and the possible Japanese turn to the UK for nuclear assistance.

Although the Gore bill was defeated, the fact is that it was passed by the Senate and only missed by a hair in the House. Disregarding the general belief that the legislation was politically inspired, we feel that the sentiment reflected in the considerable strength that was mustered in favor of the bill constitutes a mandate for accelerating our nuclear power program in some manner. The Atomic Energy Commission and U. S. industry must not stand by and assume that the failure of the bill to pass put the stamp of approval on the present program; nor should it be assumed that such legislation is a dead issue.

Rather, the everything-is-okay-with-the-atom attitude should be set aside in favor of a searching examination of what positive steps can be taken to overcome present views of the U. S. program. If this is not done, the industry and the country may have foisted upon it ideas that will be to the long-term detriment of the whole enterprise.

IMAGINATION needs to be brought to bear on what should be done about both our domestic and foreign programs. At home, efforts can be increased through one of three paths: industry going it alone, industry sharing the risk with the government in something like the demonstration programs, or government going it alone. Because it is expected that one of the three is going to "happen," the choice is really up to industry as to which one it should be.

Thus far, industry has done a tremendous job in pushing ahead despite sparse short-term possibilities of financial return. But now is the time that real daring is called for. To demonstrate belief in the future of nuclear power as a vital force in this country, to influence the future course of the development, the electric power industry must in the next four months stake out a program that will leave no question about U. S. leadership. Money talks and enough of it has to be laid on the line to build perhaps three more sizable plants.

Combined with this, we should move forward with our foreign program. Once again, hardware that can be felt with the hands must be put up. One way would be to offer other countries inducements to buy U. S. power reactors similar to the way we're paying $350,000 towards the cost of research reactors. For example, we might pay for the difference between the cost of a conventional power plant of a particular size in a particular country and the cost of having U. S. industry build a nuclear power plant there, or maybe the differential between operating costs should be the basis for support. Special arrangements would be made, similar to those AEC has in connection with the Shippingport PWR, for the U. S. to have access to information and experience developed. All would benefit from this plan—the foreign countries, the U. S. as a country, and U. S. firms.

Regardless of what's done, there's a deadline for coming up with a plan. That's January 3, 1957, the date Congress reconvenes. Action is needed before then if those with the closest interest in atomic energy are to have any influence on what happens.

This improved Cenco Cylindrical Oven

gives you

Constant Temperature with PRECISION CONTROL

No. 95051 Cenco Cylindrical Oven, 115-230 volt, 50-60 cycles, **$165.00**.

For drying, embedding, moisture determination and similar laboratory operations, this oven provides the most satisfactory and dependable means available. It may be set for automatic regulation from approximately room temperature to 210°C. Precision of control is plus or minus 1° at 100°C. The oven is ruggedly constructed and insulation is extra heavy. Heating elements completely surround the chamber insuring uniform heat distribution. Where low temperature procedures are required, a vacuum chamber is available for inserting into the oven.

cenco

The most complete line of scientific instruments and laboratory supplies in the world

RS

Central Scientific Company

1736 IRVING PARK ROAD, CHICAGO 13, ILLINOIS

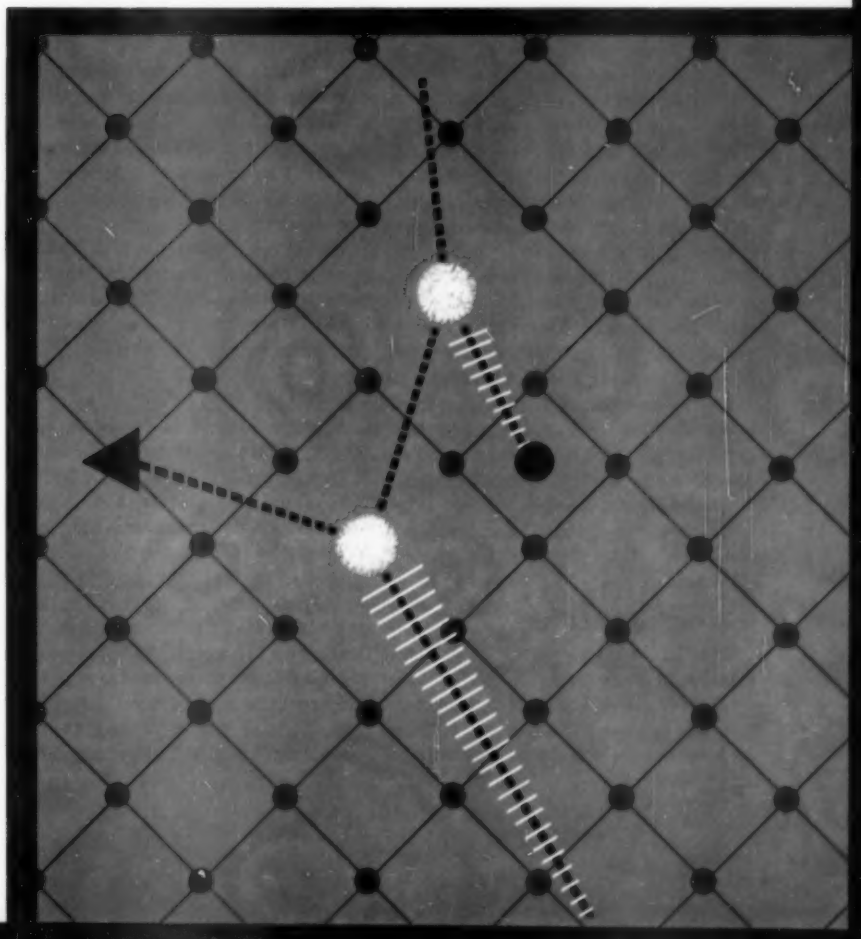
BRANCHES AND OFFICES—CHICAGO • NEWARK • BOSTON • BIRMINGHAM • DETROIT
SANTA CLARA • LOS ANGELES • REFINERY SUPPLY COMPANY—TULSA • HOUSTON
CENTRAL SCIENTIFIC CO. OF CANADA, LTD.—TORONTO • MONTREAL • VANCOUVER • OTTAWA

It has been said many times that radiation is here to stay and that man has got to learn to live with it. This usually refers to environmental radioactivity. But the same general philosophy also applies to the nuclear design specialist who needs to take radiation into account in the selection of materials and components for nuclear systems. Sometimes he's got to worry about the detrimental effects of radiation. Sometimes he's able to make use of possible beneficial effects of radiation.

Whatever the case, there's one thing that's certain—there's little data available on radiation effects and what there is is not too thoroughly understood nor available in collated form.

In this special report, the Editors of NUCLEONICS have assembled material that gives a picture of where we stand in our knowledge of the subject and collects data that will be useful to the nuclear designer.

How Radiation Affects Materials



Basic Mechanisms

By D. S. BILLINGTON
Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

A NUCLEAR REACTOR can be considered, among other ways, as a copious source of high-energy radiation. This radiation can induce pronounced changes in reactor components. Under unfavorable conditions a reactor has the potential for self destruction through damage to its structural materials, even though its behavior from a nuclear standpoint is ultra safe.

Why "Damage"?

Radiation-induced changes in a solid may be deleterious from the standpoint of continued use as part of a reactor structure. This degradation has been popularly termed "radiation damage." The term "Wigner effect" is also often used, and most properly. E. P. Wigner was the first to point out the possibility of damage before it was observed experimentally in a reactor (*1*).

It should be noted, however, that not all radiation-induced changes in solids are harmful. Electron bombardment, for example, improves the temperature stability of polyethylene. And the increase in yield strength of a metal is not harmful, though the attendant decrease in ductility may be. In the main, *damage* is the principal result because materials that go into a reactor are normally in an optimal condition. Thus any change is usually deleterious.

Information Needed

The future development of nuclear reactors must depend strongly on the designers' ability to compensate for potential radiation damage. Unfortunately our state of knowledge is such that one cannot readily compile handbook-type information. There are several reasons.

First, the experimental difficulties are such that obtaining data is a slow, tedious, and potentially hazardous undertaking.

Second, the behavior of reactor materials in a radiation environment is sufficiently different from behavior in conventional environments to forbid strict interpretation in terms of the conventional environments. We are faced with a long period of difficult experimentation before we can accumulate sufficient data to permit an engineering "feel" for the subject. We do not have the insight or information to permit us to write specifications for materials in terms of potential radiation damage.

Third, the present availability of suitable research reactors is not sufficient to meet the demands of a comprehensive program. This situation will remain for several years.

Better Flux Measurements

A primary need is for better flux measurements. One expects damage to be influenced by the rate of introduction of defects; that is, the neutron flux. Most materials are obviously affected by the total dosage, but understanding in regard to flux is still lacking in most materials. The lack of suitable facilities has an important bearing on this point.

A qualitative theory for the radiation damage process has been developed over the past several years, that gives some insight into the mechanisms and a feel for the scope of the field. But a detailed description is not yet possible. Quantitative understanding is lacking and awaits progress in defect-solid-state knowledge. This undoubtedly will be aided by appropriate experiments in the radiation-damage field.

Optimistic Outlook

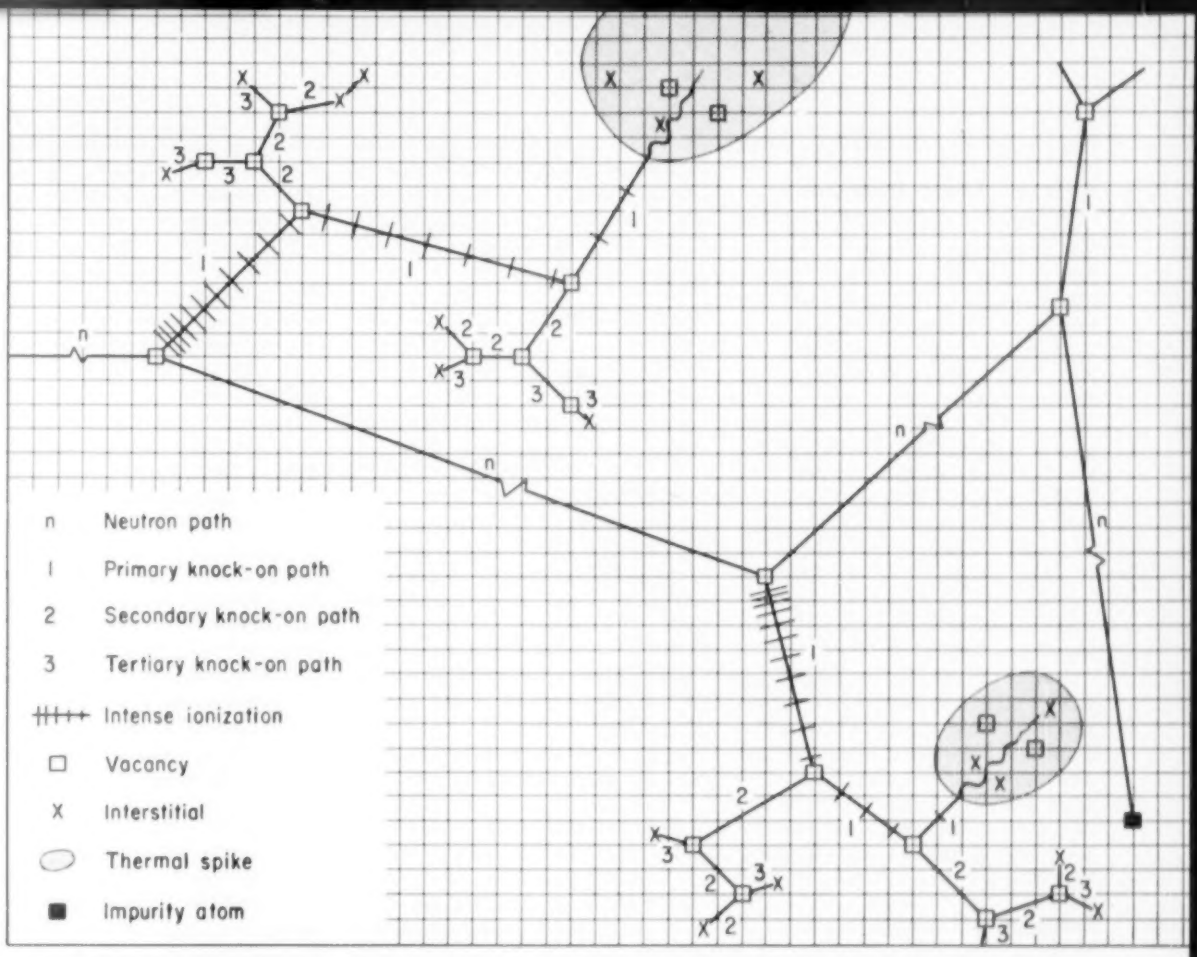
The above points, while pessimistic in tone, should not be interpreted as implying hopelessness; on the contrary the over-all situation is optimistic for most potential reactor designs. We have come a long way not only in understanding but in practical results. We have in operation a wide variety of reactors. We understand, for example, that neutron irradiation does not result in a catastrophic increase in creep rate at low fluxes as was earlier supposed.

Radiation damage *is* a very complex subject. In its simplest terms it is a merger of solid-state physics with nuclear physics and chemistry. Few if any of the complexities of each are left out.

Breadth of Field

The worker in the field must not only understand the object of study. He must be well informed in many aspects of reactor engineering, including shielding, production of isotopes and radioactivity, criticality studies, and flux measurements.

Problems of shielding and radiation damage are related in a complementary manner. Those who study shielding are concerned with the attenuation of nuclear radiation in its passage through solid matter. The student of radiation



THE FIVE PRINCIPAL MECHANISMS of radiation damage are ionization, vacancies, interstitials, impurity atoms, and thermal spikes. Here is how a neutron might give rise to each of them in copper. Grid-line intersections are equilibrium positions for atoms

damage is concerned with what happens to the solid matter during the attenuation process. The same equations must govern many of the calculations of both workers. Practically, the attenuation process may in time render the material unsuitable for shielding purposes.

DAMAGE MECHANISMS

Radiation damage originates from the interaction of energetic radiation and matter (*2*). This interaction displaces atoms from their equilibrium positions and places them in nonequilibrium positions. It creates transient, local high-temperature regions. It introduces impurity atoms either through radioactive capture and decay or by inclusion of fission fragments. And it breaks chemical bonds and forms free radicals.

The results of these effects we list by the five names: vacancies, interstitials, thermal spikes, impurity atoms, and ionization effects. All will cause changes in many of the properties of matter, whether it be solid or liquid.

The first four items are of most concern to those who deal with solid reactor components. The last is of concern in liquids and gases. It is the principal topic in radiation chemistry.

Estimates of Magnitudes

Numerous theoretical estimates have been made of the number of vacancies and interstitials that are created per incident neutron and fission fragment. Sizes and durations of thermal spikes accompanying the collision process have been estimated (*3*, *4*). These calculations are difficult to check experimentally. The effect per defect on properties such as electrical resistivity is not known with sufficient accuracy. Where experimental verifications have been attempted, it appears that theory leads to an overestimate of the number of defects by a factor of 2–5.

On the other hand, where the effect of radiation is to enhance solid-state reactions that are diffusion controlled, it is found that the number of defects required has been underestimated.

Defect Behavior

At the present time experiment and theory apparently agree within an order of magnitude, but closer agreement will depend in large measure on gaining additional information on the behavior of defects in general. In the case of radiation damage, it is clear that we must be dealing with a collection of defects that react with the matter and with one another in a fashion not clearly understood.

It has recently been shown that when radiation experiments are carried out at a temperature low enough to inhibit all defect motion, it is useful to consider the damaged region as resembling a frozen-in liquid (*5*, *6*). Surprisingly, defect mobility has been observed at −243° C (*7*, *8*). Type and extent of defect motion in a solid is a function of the type and structure of the solid containing the defects. The effect of radiation on the behavior will depend also on the latent opportunities for change

that already exist in the solid material.

Neutrons, Fission Fragments

The nuclear particles in a reactor that cause most of the radiation damage in solids are fast neutrons and fission fragments, chiefly because the energy of each is tremendous in relation to the energy required to create a defect. The uncharged nature of the neutron means that it can interact only by direct collision. However, once a collision has taken place, the knocked-on atom in turn rapidly creates subsequent displaced atoms. The incident neutron travels many thousands of atomic spacings in the solid before it makes another collision. Thus the damage resulting from fast neutrons is widely spread through a reactor, affecting all components.

Fission fragments, possessing initially a high charge and mass must dissipate all their energy within a few microns. Therefore the damage is usually confined to the fuel volume. The total energy dissipated in radiation damage is approximately the same for both types of particles, but the spatial distribution is very different.

Betas and Gammas

Other nuclear radiations such as beta particles and gamma rays are also capable of creating damage. But in general the amount is trivial in comparison with that of fast neutrons and fission fragments. The momentum that can be transferred to a lattice atom from these radiations is small.

On the other hand, in studies of the basic nature of radiation damage, light particles are of interest because of the simpler nature of the defects that they create. It has been demonstrated in the case of electron bombardment that one can determine the energy required to create a vacancy in a solid (*9, 10*). This is a unique and useful measurement that is not complicated by the presence of additional defects such as thermal spikes, induced radioactivity, and impurities. These always accompany fast-neutron- or fission-fragment-induced radiation damage.

HOW DAMAGE OCCURS

Our present knowledge of defect solid state does not allow a detailed description of how defects probably cause damage. Still we have a reasonable qualitative picture of the processes.

Vacancies

For example, it is now reasonable to assume that the intermingling of atoms in the solid state depends on vacancies and that at any given temperature there is an equilibrium number of vacancies present. The larger the number of vacancies, the more rapidly diffusion takes place. Thus creation of excessive vacancies by radiation should result in increased reaction rates at a given temperature.

Two experimental observations appear to be consistent with this viewpoint. First, a disordered Cu_3Au specimen can be ordered during exposure at temperatures well below those at which ordering normally occurs (*11*). Second, the precipitation process in Cu-Be alloy can be speeded up as a result of bombardment (*12*). This enhancement of diffusion takes place on a microscopic scale only. It has not yet been shown that appreciable changes in mass-transfer rates can be achieved under irradiation.

Interstitials

The behavior of interstitials is more difficult to understand, but the pronounced increase in yield strength that accompanies even moderate neutron irradiation of a metal leads one to believe that interstitials may be playing an important role in the hardening reaction, though it must be acknowledged that a suitable mechanism has not yet been devised that leads to detailed understanding.

The problem of understanding the behavior of interstitials stems partly from our inability to create interstitials in close packed good metals by measures other than irradiation.

Impurities

Impurity atoms can be understood in conventional terms. Usually the number introduced is small, and the effect is small compared to other damage effects. Thus in materials suitable for reactor applications this problem usually can be neglected. In the matter of fission fragments, however, the impurity effect is of much greater magnitude. The production rate is higher, and the size and character of the fragments is such as to render them normally insoluble in the parent matrix. This leads to enhanced strain effects, and it is readily observed that a residual effect of appreciable magnitude remains after all other types of damage have been annealed. On the other hand the fuel material does not have the permanent residency of other components, so removal for reprocessing eventually corrects fission-fragment damage.

Thermal Spikes

The thermal spike presents the most controversial aspect of radiation damage. It results from that portion of the energy that is stored in the form of displaced atoms or trapped electrons and is dissipated as heat during the collision process. The amount is comparable to that dissipated in the formation of Frenkel defects. It has been generally supposed that this energy creates a momentary region of high temperature that in a good metal may involve thousands of atoms and result in an increase in temperature of 1000° K for probably less than 10^{-10} sec. With fission fragments the number of atoms involved and the temperature increase would be correspondingly greater.

A number of low-temperature experiments have shown that the thermal spike may act as a source of vacancies and interstitials but does not directly cause radiation damage (*13*). In other words the thermal spike may create a frozen-in liquid-like region that upon subsequent warming may liberate vacancies and interstitials (*14*). Further-

Many Things to Many Men

Radiation damage is somewhat unique in that it can be considered in so many different ways:

The **materials engineer** *views the field simply as an additional environmental factor to be considered.*

The **metallurgist** *sees it as another technique for altering the properties of a metal or alloy. It belongs in a category with cold working, alloying, and heat treating.*

The **physicist** *considers it as a portion of the larger field of defect solid state.*

The **chemist** *sees a technique for altering the course of chemical reactions.*

The **safety engineer** *sees another potential hazard.*

There is truth in all these viewpoints.

more, the effect may be overestimated in the case of metals. Its existence as a major effect in fission-fragment damage is probably better founded.

The thermal spike was first utilized to explain the *disordering* effect in Cu_3Au (*4*). However, it has recently been shown that if one uses a replacement concept instead of a displacement concept, even the disordering data can be explained without a thermal spike (*15*).

The thermal-spike concept, while useful, will require more study before it will emerge as a quantitative tool in the interpretation of radiation damage.

Variation with Material

In any attempt to anticipate radiation damage under reactor operating conditions, it is difficult to make universally applicable generalizations. The type of damage and its extent depend strongly on the type of solid that is bombarded.

The damage process alters certain properties to a far greater extent than others. For example, in representative metals and alloys one observes sharp increases in the yield strength after modest radiation doses (*16*). Ductility often is reduced appreciably as well. On the other hand, one does not expect or observe significant changes in thermal or electrical conductivity when metals or alloys are bombarded at reactor ambient temperatures.

Nonmetals. Nonmetallic compounds exhibit variable behavior. Materials like Al_2O_3, MgO, NaCl may show moderate electrical, thermal, and optical changes, but they do not show extensive density changes. They do show an increased susceptibility to fracture. Compounds such as quartz reveal large density and structural changes after moderate irradiations but are able to maintain macroscopic integrity (*17*).

Semiconductors. Semiconductors are extremely sensitive to radiation. This is shown by the drastic change in electrical conductivity and in a change in the character of the conduction. The conduction may change from electron to hole conduction and vice versa, with short exposures. The nature of the change depends on the original state of the material (*18*).

Plastics, elastomers. Plastics and elastomers, too, are sensitive to nuclear radiation (*19*). The changes from moderate dosages range from complete disintegration and embrittlement to only discoloration. Quantitative data on threshold for damage and for ultimate failure are discussed in the following article of this report.

Thus, specification of a particular material and a specific property are required in order to make any estimation of probable damage. In addition to these aspects, environmental conditions will play a strong role.

Effect of Temperature

The temperature is most important in any consideration of the damage process in a crystal since the temperature will determine the subsequent behavior of the defects introduced by irradiation. Very low temperatures (−253° C) will cause the defects to be completely immobile. Thus they are retained, and changes in properties like electrical conductivity that depend only on the presence of defects will be increased at low temperature. Thermal conductivity of nonmetals at low temperatures is greatly decreased because of the effect of defects on lattice conduction. This type of conduction is of chief importance at these temperatures in insulating materials.

If the subject of irradiation is either a metastable metallic or nonmetallic alloy, enhanced diffusion effects that result in the conversion of the material to the stable phase can be observed. The temperature must be high enough to permit diffusion to take place. At low temperature these effects are repressed. The critical temperature for these effects is a function of the temperature dependence of diffusion in the material under consideration. In copper beryllium, precipitation can be observed during room-temperature irradiation, in nickel beryllium the metastability is preserved at room temperature but can be observed at 200° C and higher (*20*).

Irradiation of ZrO_2 at room temperature results in the disappearance of the monoclinic phase (*21*). However, subsequent annealing at elevated temperatures will cause the material to revert to the stable configuration. Many additional examples of the importance of the temperature of irradiation are available in the literature (*22*).

Other Influences

Several other aspects of materials may influence behavior under irradiation. Particularly important are anisotropy, history, impurities, and surface conditions.

It has been repeatedly observed that materials possessing highly anisotropic characteristics such as metallic uranium and graphite will show an enhancement of the anisotropic properties under irradiation. The history of a given material may determine the susceptibility of a material to damage. Thus quenched or cold worked metals and alloys may show anomalous density and dimensional changes when irradiated. Small amounts of impurities of high cross section material such as boron and lithium may result in enhanced radiation effects because of the (n, α) reaction. The surface condition may influence the chemical reactivity induced by the irradiation.

Implications

The necessity for the control of the structure sensitivity of solids preparatory to use in a nuclear-reactor-radiation field is just as important as in any other usage where structure-sensitive properties play an important role.

Specifications of materials for reactor use require criteria that are not a part of conventional specifications since all pertinent property changes found under irradiation are not consistent with behavior in the absence of radiation.

BIBLIOGRAPHY

1. E. P. Wigner, *J. Appl. Phys.* **17,** 857 (1946); Milton Burton, *J. Phys. & Colloid Chem.* **51,** 611 (1947)
2. F. Seitz, *Discussions Faraday Soc.* **5,** 271 (1949)
3. H. Brooks, KAPL-360 (1949)
4. S. Sigel, *Phys. Rev.* **75,** 1823 (1949)
5. A. Seeger, *Z. Physik* **130,** 251 (1955)
6. T. H. Blewitt, private communication
7. H. G. Cooper, J. S. Koehler, J. W. Marx, *Phys. Rev.* **94,** 496 (1954)
8. T. H. Blewitt, *et al*, *Phys. Rev.* **98,** 1555 (1956)
9. E. E. Klontz, K. Lark-Horovitz, *Phys. Rev.* **86,** 643 (1952)
10. J. M. Denny, *Phys. Rev.* **92,** 531 (1953)
11. T. H. Blewitt, R. R. Coltman, *Phys. Rev.* **85,** 384 (1952)
12. G. T. Murray, W. E. Taylor, *Acta Met.* **2,** 52 (1954)
13. J. W. Cleland, D. S. Billington, J. N. Crawford, *Phys. Rev.* **91,** 238 (1953)
14. T. H. Blewitt, private communication
15. G. H. Kinchin, R. S. Pease, *Jour. Nuclear Energy* **1,** 200 (1955)
16. T. H. Blewitt, R. R. Coltman, *Phys. Rev.* **82,** 769 (1951)
17. M. C. Wittels, *Phys. Rev.* **89,** 656 (1953); W. Primak, L. H. Fuchs, P. Day, *Phys. Rev.* **92,** 1064 (1953)
18. J. W. Cleland, J. H. Crawford, K. Lark-Horovitz, F. W. Young, *Phys. Rev.* **83,** 312 (1951); J. W. Cleland, J. H. Crawford, *Phys. Rev.* **95,** 1177 (1954)
19. O. Sisman, C. D. Bopp, NUCLEONICS **12,** No. 10, 51 (1955)
20. R. H. Kernohan, D. S. Billington, A. B. Lewis, *J. Appl. Phys.* **27,** 40 (1956)
21. M. C. Wittels, F. A. Sherrill, *J. Appl. Phys.* **27,** 643 (1956)
22. J. C. Wilson, D. S. Billington, *J. Metals* **8,** 665 (1956)

Importance of Various Factors in Causing Radiation Damage*

	Gamma Radiation	*Thermal Neutrons*	*Epithermal Neutrons*	*Fission Fragments*	*Dose Rate*	*Environment*	*Temperature*	*Stress*	*Initial State*
Metals, nonfissile	L	L†	H	H‡	?	M?	M	?	M
Ceramics	L	L†	H	H‡	?	?	M	?	M
Plastics and elastomers	H	L†	H	L§	H?	H	H	H	H
Fuels	L	H	H	H	?	?	H	?	H
Control and shield elements	L	H	H	L§	?	?	M	?	H
Electrical components*	H	L†	H	L§	H	H	H	M	M
Liquids (except metals)	H	L†	H	L§	L	L	H	L	L

H, High; M, Medium; L, Low; ?, Unknown. * Permanent change only, for all except electrical components. † For low-cross-section materials. ‡ When in contact with fuel. § Which are normally not in contact with fuel

Engineering Use of Damage Data

By O. SISMAN and J. C. WILSON
Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

AT THIS EARLY DATE in the development of power reactors, interpretation of radiation-effects data is a most difficult task for the engineer who must incorporate the data into design. The problem is difficult because there is little data. Also, interpretation of the data in terms of unique conditions in reactors and in terms of unfamiliar properties bestowed on familiar materials by irradiation, must be made without the extensive background of service experience upon which evaluation of engineering data usually is based.

To compile a handbook of radiation effects for general use at this time would be misleading because the interpretation of the data, not the data itself, is the important consideration. This article points out the important variables and outlines a framework for interpretation of radiation-effects data for the engineer.

Engineering Methods

Normally the engineer makes an estimate of safe operating conditions. But to do this he must face such difficult-to-answer questions as: When will a pressure vessel be subject to brittle fracture? When will a gasket leak? When will a bearing freeze? When will a pump stop pumping? To find answers he must look at certain readily accessible properties of materials: tensile strength, impact strength, viscosity, corrosion, etc.

The first step in establishing a tolerance radiation dose is then obvious. A tolerance change in some property or properties of the material must be established. The tolerable change may be quite large for one application and extremely small for another. The tolerable change in viscosity of the oil in which a sensitive instrument runs would have to be very small. The tolerable change in tensile strength of a structural member might be fairly large. The important point is that some tolerance must be established, no matter how small.

For unirradiated components there is usually available operating data from which to get the characteristics of operation and the expected lifetime of the component. There is almost no data of this type for irradiated components, so the effect of radiation on the component must be judged by the effect on the materials from which it is made. Often there is insufficient data to establish the radiation dose that is tolerable, but a limiting dose usually can be established below which the radiation effect is unimportant. For some materials an upper limit can be established—above which the material is completely unusable. The approximate radiation doses for a few important effects are presented in Fig. 1.

If it has been established that there is a problem—i.e., that the proposed irradiation dose is greater than that for which no damage has been observed and less than that for which there is no hope of using this material—then one can proceed to determine what can be done about it. In some cases the radiation-damage data may be good enough to establish a lifetime for the component in the radiation field. In other cases additional testing is indicated. Sometimes the particular material is

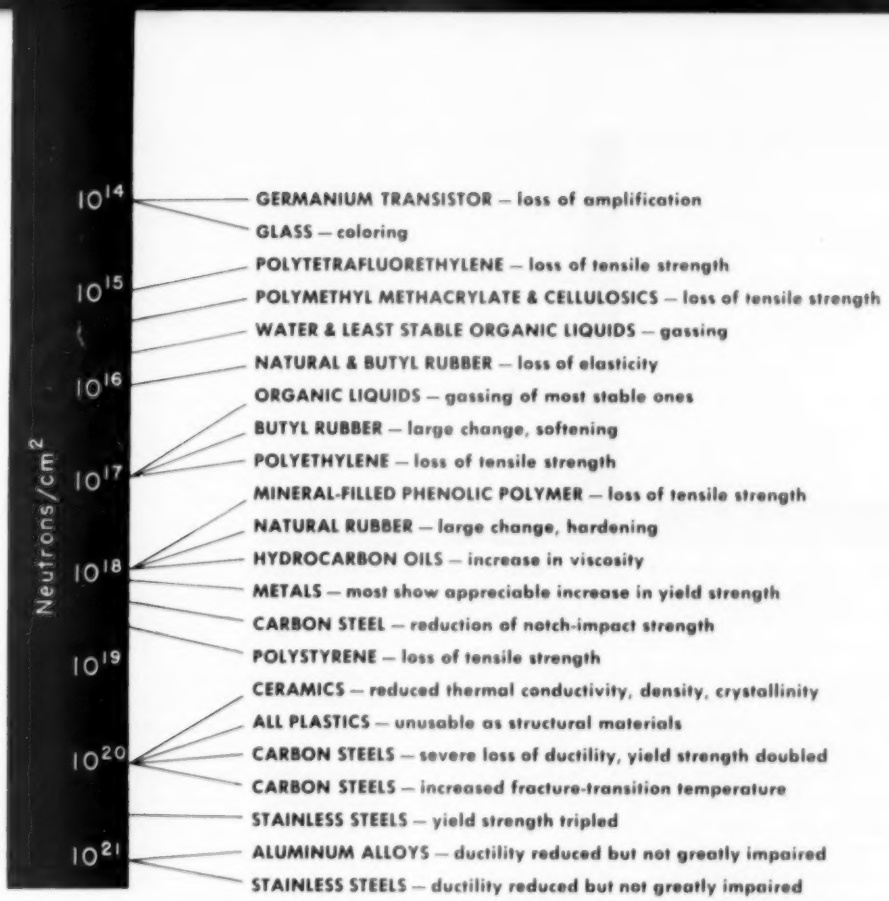

Neutrons/cm²
10¹⁴
10¹⁵
10¹⁶
10¹⁷
10¹⁸
10¹⁹
10²⁰
10²¹
GERMANIUM TRANSISTOR — loss of amplification
GLASS — coloring
POLYTETRAFLUORETHYLENE — loss of tensile strength
POLYMETHYL METHACRYLATE & CELLULOSICS — loss of tensile strength
WATER & LEAST STABLE ORGANIC LIQUIDS — gassing
NATURAL & BUTYL RUBBER — loss of elasticity
ORGANIC LIQUIDS — gassing of most stable ones
BUTYL RUBBER — large change, softening
POLYETHYLENE — loss of tensile strength
MINERAL-FILLED PHENOLIC POLYMER — loss of tensile strength
NATURAL RUBBER — large change, hardening
HYDROCARBON OILS — increase in viscosity
METALS — most show appreciable increase in yield strength
CARBON STEEL — reduction of notch-impact strength
POLYSTYRENE — loss of tensile strength
CERAMICS — reduced thermal conductivity, density, crystallinity
ALL PLASTICS — unusable as structural materials
CARBON STEELS — severe loss of ductility, yield strength doubled
CARBON STEELS — increased fracture-transition temperature
STAINLESS STEELS — yield strength tripled
ALUMINUM ALLOYS — ductility reduced but not greatly impaired
STAINLESS STEELS — ductility reduced but not greatly impaired

FIG. 1. Sensitivity of engineering properties to radiation. There is wide variation in effect of irradiation on various materials. Levels indicated are approximate and subject to variation. Irradiation dose is in epithermal neutrons. Indicated changes are in most cases at least 10%

altogether unsuitable for a proposed use in a radiation field, and a new design is required using another material.

There are often two other alternatives: the component can be moved to a region of lower radiation intensity, or it sometimes can be shielded. In any event the problem should be carefully considered, and the more radiation-stable materials should be used where possible so as not to place an excessive burden on the designer.

Structural Metals

Structural metals usually are evaluated by strength, ductility, and impact tests. But the integrated-flux dependences of different properties are not the same. This is shown in Fig. 2. In normal structural materials the strengths (tensile and ultimate) invariably are increased with sufficient radiation at ordinary temperatures. This may not be so at higher irradiation temperatures.

The strength in creep and in fatigue have only been determined under a few conditions; these properties deserve more attention. A strength increase usually is regarded as beneficial if there is no concurrent loss in ductility. Some ASTM standards specify a maximum ultimate strength, and irradiation can cause carbon steels to exceed the maximum. In structures where some plastic flow normally is expected, increased strength can be objectionable—it may lead to high elastic stresses that normally would be relieved by deformation or stress relaxation.

Ductility limits. Ductility (in the tension test) normally decreases after irradiation. The difficult problem is to set limits on the allowable decrease, because it is not yet possible to assess quantitatively the meaning of the ductility values. Radiation can reduce the ductility (in the tension test) below the minimum in ASTM specifications.

The loss of energy absorption in the notch-impact test and the increase in the fracture-transition temperature has been some cause for concern in irradiated steels. The minimum values specified for the notch-impact test are the result of service experience; the level of energy absorption required appears to depend on structure or heat treatment, and radiation could well act to modify the necessary, safe, minimum level requirements.

Changes in behavior. The behavior during mechanical testing of carbon and stainless steels, shown in Fig. 3, has suggested that the response of these materials to stress is changed by radiation. For instance, stainless steels show a yield point, and the yield stress is strain-rate dependent. This has suggested that the conventional interpretation of mechanical tests may not be applicable to irradiated metals.

Another consideration in evaluating metals is that the stress, strain, and time conditions in a reactor may be different than in other structures. The fatigue properties in reactor pressure vessels may be a major factor because of the thermal-stress conditions during startup and shutdown.

Plastics and Elastomers

Since they are basically organic polymers, the changes in the physical prop-

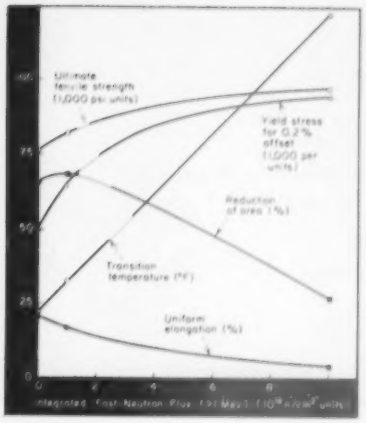


FIG. 2. Integrated-fast-neutron-flux dependence of several mechanical properties of A-212B carbon-silicon steel

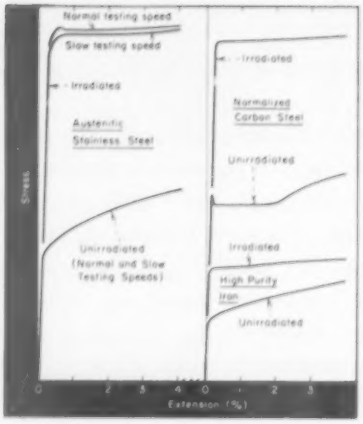


FIG. 3. Behavior of steels and iron in tensile test. Irradiation changes shape of curves and rate of work hardening

erties of plastics and elastomers are reflected in the extent of two reactions of the polymer—crosslinking and cleavage. Some of the engineering properties associated with cleavage and crosslinking are summarized on page 61.

Chemical changes. Chemically, polymers are altered quite drastically. Aside from the crosslinking and cleavage reaction, which produces most of the physical change in the material, there is usually a variety of side reactions. The production of gas is a direct result of crosslinking, but it also may come as a side reaction. Often unsaturation is produced, but double bonds may be destroyed also. Sometimes increased chemical reactivity is indicated by both increased solubility and the production of corrosive byproducts. Increased water absorption sometimes is observed. The crosslinked materials are harder to dissolve and harder to melt.

Dimensional changes. In this class of materials dimensional changes can be extremely large. In general, crosslinking causes an increase in density by reducing the specific volume of the material, and many plastics do show a large shrinkage effect. However, due to the formation of gas, there is also very often a swelling effect and a large decrease in density.

Electrical changes. Permanent electrical changes are usually not serious before mechanical failure occurs. However, while the material is in the radiation field, the electrical properties may change drastically. The change is greatest for the best insulators.

Discoloration. Many plastics discolor, and transparent materials may transmit less light. But some crystalline materials become more transparent because radiation destroys the crystallinity. The color in plastics, caused usually by decomposition products, normally cannot be removed by heat. Darkening is sometimes prevalent in the presence of oxygen when it may not occur without oxygen.

Mechanical changes. The early changes in some of the properties of plastics are often an improvement. Increased tensile strength and increased softening temperature that accompany crosslinking are desirable changes. However, some of the accompanying changes, like increased hardness and decreased elongation, may not be desirable. Even though some of the improvements in properties may occur before any serious less desirable changes, for the engineer this is usually a sign of impending radiation damage. With further irradiation the strength will decrease and embrittlement may be followed by cracking and powdering.

The elastomers that harden decrease in tensile strength to almost zero and then have a very large sudden increase in strength (Fig. 4). At this point the elastomer has been changed to a glass, and, with further irradiation, has the radiation-damage characteristics of a glass. (This rubber to glass transition can be brought about by other means too, such as lowering the temperature). For an application (a seal, for example) where a rubber need not retain its elastomeric properties, it may be considered for a much longer life in a radiation field.

Ceramics

Many materials that fall into the class of ceramics are being studied quite intensively from a fundamental standpoint, but the engineering properties are just now beginning to receive attention. For reactors there is a great deal of interest in ceramics as high-temperature materials. Here very little data is available.

As a class the ceramics are much more radiation resistant than organic materials, but will probably suffer more damage than most metals. Ceramics generally are not used where great strength is required, but not much loss in strength is seen for moderate irradiation periods. Swelling, or a decrease in density, is observed for most ceramics. But some glasses increase in density, presumably because radiation is completing the annealing processes that was not allowed to go to completion during manufacture.

Disordering, coloration. Crystalline materials are fairly readily disordered by fast-neutron bombardment, and the same materials show an early decrease in thermal conductivity. However, the thermal-conductivity change may be due at least partially to impurity atoms introduced by transmutation by thermal neutrons.

Coloration, particularly noticeable in some glasses, is caused by the formation of *F*-centers, and is readily cleared up by heat. Since much of the radiation damage in ceramics can be annealed out, it is often assumed that ceramics irradiated at high temperatures will suffer little damage. This has not yet been established experimentally.

Fuels, Control Rods

Fuels, of course, suffer heavy radiation effects because of fission. Most of the damage results from fission fragments and fast neutrons. But a large number of impurity atoms are introduced as a result of fission also. Since the fuel normally is not required to perform any structural function except holding itself together; and since, in addition, the fuel does not remain in the reactor very long, the radiation-damage requirements are not too severe. Most troubles are encountered from dimensional changes and separation of the cladding from the fuel.

Control or shield materials can be

expected to suffer larger radiation effects than the average metal or ceramic because of the secondary particles from thermal-neutron capture. If the materials contain boron, they should be treated more as fuel elements than as structural materials. The B^{10} atom splits to form heavy energetic Li and He atoms capable of causing considerable displacement damage as do fission fragments. Two atoms result from each B^{10} atom split by neutron capture, and the lattice must accommodate the extra atoms.

Most of the fuels and control-rod materials are metals. Thus, most of the radiation-damage data are on metallic elements. There is an increasing interest in ceramics and liquids for this application.

Semiconductors*

Components employing semiconductors are among the most easily damaged by radiation. The amplification of a transistor, for example, is greatly reduced at a radiation level that does not affect even the least radiation-stable organic material.

The effect of radiation on semiconductor components is eventually to destroy the component. The destruction of barriers in junction devices such as rectifiers and transistors usually occurs at a low integrated flux compared to the dose required to produce a comparable change in most materials. Thus the collector leakage current of a transistor and the reverse saturation current of a rectifier will change by orders of magnitude before an appreciable change can be detected in the emitter current of the transistor or forward current of the rectifier.

There are three ways in which radiation can affect the properties of a semiconductor device: transmutation, photoelectric effect, and lattice disturbance. Thermal neutrons captured by the semiconductor produce excited nuclei that decay to form impurity atoms. The absorption cross sections, isotopic abundances, and decay schemes are well known for those semiconductors most widely used. Hence the effect of thermal-neutron irradiation is to introduce a predictable number of impurity atoms.

Neutrons having sufficient energy to produce displaced atoms cause regions of disorder in the semiconductor crystal. This changes the carrier concentration and thus the conductivity of the material. These displacements change *n*-type germanium to *p* type. Silicon does not change the sign of the carriers, but both *n* and *p* type decrease in conductivity as the number of displaced atoms increases.

* J. C. Pigg, ORNL, personal communication.

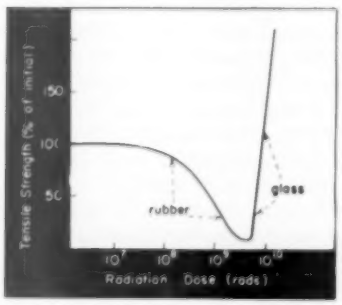


FIG. 4. Break in plot of tensile strength vs radiation dose indicates rubber-to-glass transition of natural rubber

How Organics are Changed by Radiation-Induced . . .

. . . CROSSLINKING

- Increases Young's modulus
- Impedes viscous flux
- Increases retardation of strain

Usually causing:

- Increased tensile strength
- Decreased elongation
- Increased hardness
- Increased softening temperature
- Decreased solubility
- Gas formation
- Embrittlement
- Decreased elasticity

. . . CLEAVAGE

- Decreases Young's modulus
- Reduces yield stress for viscous flow

Usually causing:

- Decreased tensile strength
- Increased elongation
- Decreased hardness
- Increased solubility
- Decreased elasticity

Sometimes causing:

- Embrittlement
- Gas formation

Liquids

The organic liquids important to reactor technology are lubricants, coolants, hydraulic fluids, moderators, and shields. The reactions induced by radiation are much the same as for organic solids, and the stable structures are of the same general type as has been found for organic polymers. Biphenyl is the most radiation-stable organic liquid (m.p. 70° C); terphenyls and substituted biphenyls are almost as good. The condensed-ring structures are also relatively radiation resistant and for some applications the alkyl benzenes have desirable properties.

Though a few liquids are decreased in viscosity, most organic liquids become more viscous by radiation-induced polymerization. Often a solid sludge is formed, and gassing is prevalent. Coking and the tendency to foam may be increased. Increased corrosion may result from some of the products.

In many applications where liquids are used they may be circulated from an external reservoir. This dilutes the effects of irradiation and often allows the use of a liquid that otherwise might be too badly damaged; it also allows replacement of decomposed material. A difficulty with circulating systems in a neutron flux is that radioactive materials are pumped out of the reactor and require shielding. The hydrocarbon materials are very good from this standpoint because they do not become very radioactive. But corrosion products still may be bothersome.

Water or water solutions are still the primary reactor coolants and moderators and are among the most used radiation shields. The radiation-induced reactions are being studied very intensely by radiation chemists. The principal concern of the engineer is corrosion. Second is gas and sludge formation. Most water systems can stand a fair amount of radiation without serious enhancement of corrosion.

Liquid Metals

Theoretically, none of the mechanisms of radiation damage that change the properties of other materials are operable on liquid metals, and no change is expected unless some new mechanism is discovered. No radiation-induced change has ever been observed in liquid metals.

Important Variables

Engineers are only now accumulating the data needed to meet problems of nuclear design. Much of the available data are incomplete because the importance of many variables has been realized only recently. The following conditions must be carefully and completely specified for any data to be fully useful (see Table): kind and amount of radiation, rate of irradiation

(dose rate), environment during irradiation (including temperature), and initial state of the material. To specify the last, one usually should know the prior history.

Kind of Radiation

The type of radiation is a very important consideration in evaluating radiation effects. In a reactor, the important classes of radiation that strike materials not in contact with the fuel are: thermal neutrons, epithermal neutrons (all energies above thermal), and gamma rays.

For metals and most ceramics, the energetic neutrons usually cause the only important changes. To adequately describe flux conditions, flux spectrum should be indicated. This is important because radiation-damage reactions occur at different neutron-energy levels—it takes neutrons of 1,000 ev or more to displace a metal atom from its lattice to produce an interstitial and a vacancy; it takes neutrons of about 100 ev to cause lattice expansion in a ceramic; and it takes only a few ev to break a chemical bond to cause changes in polymers.

In metals, thermal neutrons cause transmutations that may affect the properties at extreme doses—about 10^{23} nvt for steel—depending on the elements present.

For organic materials, the gamma radiation in a reactor (especially at locations where plastics are used) may be of such an intensity as to be more important than fast neutrons. Although organics suffer from collision reactions with heavy particles, they generally suffer much larger effects from the ionization and excitation produced by the secondary particles created in the collision reaction and by the secondary electrons produced in stopping the gammas. For all but the very rigid organic solids, the change produced by radiation is proportional to the energy absorbed (regardless of source—whether it be gammas or neutrons or another kind). Thus, the radiation dose is best expressed in ergs or rads per gram of material.

Materials in contact with reactor fuel suffer greatest damage by fission fragments. Principally, they damage organics by ionization, and they damage metals by displacing atoms and by introducing impurity atoms into the lattice.

Dose Rate

If most data have been determined at radiation dose rates comparable to the dose rate for the expected service, it is reasonable to assume that the effect is proportional to the integrated dose. For large differences in dose rate an estimate of the radiation effect based on this assumption may be in error. Competing reactions may go at different rates for different levels of radiation.

Liquids. So far the dose rate appears to be unimportant for liquids. Most of the data for organic liquids is for dose rates of the order to 10^6 rad/hr or less, and only a few special cases of inorganic liquids have received higher dose rates than this. Since the molecules in a liquid are mobile, the dose rate at which the chemical reaction rate is slower than the formation of free radicals is very high.

Solids. For organic solids, a dose-rate effect has been observed for a few materials, but very little data are available. One expects the dose rate effect to be more serious for the rigid materials, in which the molecules have decreased mobility, than for soft plastics and elastomers. The effect that has been observed is to increase damage per total dose for low dose rates.

Metals. For metals, no dose-rate data have been obtained. In dynamic properties such as creep or fatigue there should be a rate effect during irradiation. Dose rate may be important where several competitive processes are acting simultaneously.

Environment

There are in a reactor the normal environments considered when operating other types of machines—temperature, pressure, and surrounding fluid. Added to this is radiation.

The effect of temperature on the radiation-induced reactions is especially important in power reactors, which usually operate at high temperatures. To the engineer the most important effect of increased temperature is the annealing effect, which acts to reduce the amount of damage in some metals and ceramics. However, increased irradiation temperature does not always result in a lesser change than at lower temperatures. The ultimate strength of a carbon steel may show greater increases at higher temperatures of irradiation although the amount of increase in yield stress is reduced by the higher temperature of irradiation. Plastics and elastomers, since they are not high-temperature materials, have not been studied much at temperatures different from room temperature. Since soft and elastic polymers became hard and brittle at low temperatures, the radiation effects at low temperatures will be different from those at higher temperatures.

The effects of stress on metals during irradiation are still not known. For plastics and elastomers this effect can be very large. Elastomers will suffer "ozone damage" from radiation-produced ozone or from free radicals produced by radiation if the elastomers are stressed during irradiation. Stressed polymers generally will cleave under radiation more readily than those in the unstressed condition.

In addition to the permanent change that is caused by radiation (which is the topic of this article) there is a temporary effect on the insulation properties of materials caused by the presence of the radiation field. The resistance of a good insulator may be reduced 1,000-fold in the presence of the ionization produced by the radiation field, and an induced photo-voltage is also produced.

Initial State

The initial state of a material may have an effect on radiation-induced changes. Certain physical characteristics such as crystallinity and ordered arrangements, tend to be destroyed by radiation. In general there is a decrease in density if the substance is originally in its most compact form. On the other hand, crosslinking of polymers tends to increase the density.

In metals there seems to be a great difference in radiation effects on the mechanical properties of alloys of the same nominal composition. Whether this is a composition effect of certain elements or a function of the heat-treatment and metallurgical practice is not yet known. But the fact that the susceptibility to radiation effects in similar alloys has been observed to vary by a factor of 100 (in flux) points to the importance of the initial state.

In plastics the rigidity of the material, which affects the mobility of the polymer molecule, will affect the rate of radiation damage. Unfortunately, the soft materials that are most desirable for certain applications are more easily changed than a hard material of similar chemical structure.

On Solid Reactor Materials

By J. H. KITTEL
Argonne National Laboratory, Lemont, Illinois

RADIATION HAS important effects on the engineering properties of solid materials that are used in the construction of reactors. In fuel materials only moderate irradiation produces extensive changes (*1–3*). Changes in nonfissionable reactor materials tend to be less drastic, particularly in the case of metals. Nevertheless reactor designers must include in their plans provisions for expected changes.

This article covers the important effects that have been found to affect the properties of moderators, structural materials, control materials, and shielding materials.

Moderators

Solid materials that are used as moderators are principally graphite, beryllium, and beryllium oxide. All of them show effects in their mechanical properties. In addition, graphite displays anisotropic dimensional changes and an increase in volume.

Graphite. The most widely used solid moderator is graphite, and changes produced in it by radiation have been studied more closely than those in any other nonfissionable material. It has been shown that the magnitude of radiation-induced changes depends to a large extent on the source of the graphite and the method of manufacture (*4*). The extent of radiation damage can be obtained readily by determination of the interplanar spacing, C_0. Investigators are using the change in this crystal parameter of graphite powder to determine total fast flux when conducting irradiations on other materials.

Radiation produces a stronger, harder, and more brittle graphite. Compression strength and cross-breaking strength are approximately tripled after a total neutron exposure of 2.5×10^{19} n/cm² (*4*). These changes are not always deleterious.

More serious is the change in thermal conductivity, which may decrease as much as fiftyfold. As shown in Fig. 1, this change is markedly less when exposures are made at elevated temperatures.

Of greatest interest to reactor engineers, perhaps, are dimensional changes. Most graphites have been observed to expand along planes transverse to the axis of preferred orientation and to contract along planes parallel to this axis. In addition to this anisotropic dimensional change there is a volumetric increase that proceeds steadily with increasing exposure as shown in Fig. 2. As an example of how this knowledge affects engineering design, the MTR tank is surrounded by 1-in.-dia graphite pebbles free to move so that graphite growth can be accommodated without undue stresses on the reactor structure (*5*).

When graphite is irradiated in sealed containers, an additional problem may arise because of gas evolution. However, the principal gases, CO and H_2, will be dissolved in certain container materials, such as zirconium, so that undesirably high pressures may be avoided (*6*). But in at least one zirconium-canned graphite reactor provision is being made to vent the gases from the cans (*7*).

Since all observations to date show that damage to graphite is considerably less at high temperatures than at low, one may conclude that the Sodium Reactor Experiment will produce considerably less damage in its graphite than would a similar nonpressurized water-cooled reactor operating with comparable neutron flux (*7*).

Other Moderators. Use of solid moderators other than graphite has been quite limited, but investigations have been made of radiation effects in several suitable materials. For example, beryllium, used as a reflector in the MTR, has been irradiated with fast neutron nvt's up to 1.5×10^{20} n/cm²

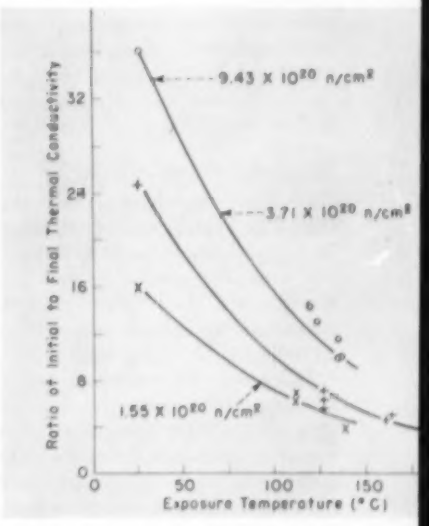


FIG. 1. Thermal conductivity of graphite decreases with irradiation, but the effect is decidedly smaller at high temperatures than at low (*4*)

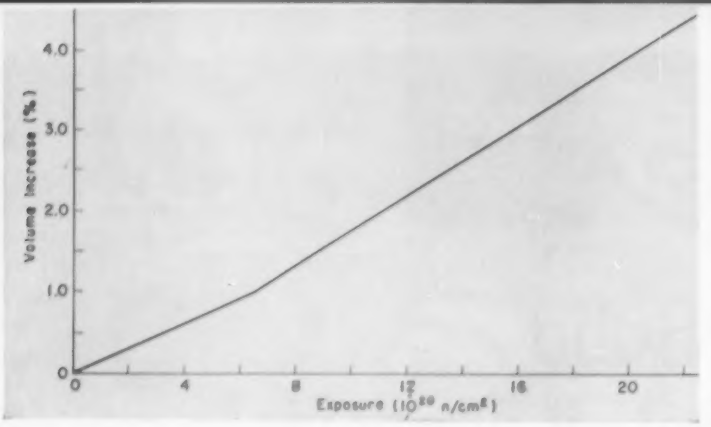


FIG. 2. Volume of graphite increases continually with irradiation (*4*). The material also displays anisotropic dimensional changes

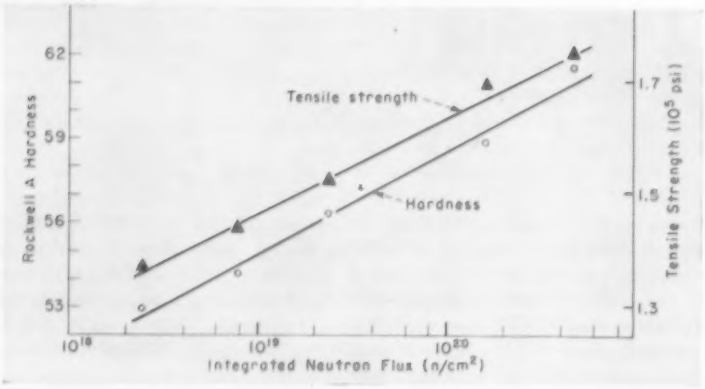


FIG. 3. Tensile strength and hardness of annealed Type-347 stainless steel increase with irradiation. Rate of increase becomes smaller (note that horizontal scale is logarithmic), but saturation is not reached at exposures shown (*11*)

(*8*). Most investigators report no significant changes in dimensions or physical properties, although a 27% increase in hardness is reported for the greatest exposure. A loss in ductility also is reported (see table).

In connection with the proposed Daniels power pile (*9*), ANL studied the effects of radiation on beryllium oxide. Dimensions and mechanical properties of BeO were relatively unaffected by several months exposure in a reactor, but thermal conductivity decreased by over 50%.

Structural Materials

Designers have used aluminum and steels for most reactor structures. Radiation damage is slight in aluminum and somewhat greater in steel. Zirconium, too, has been extensively studied for the purpose of determining its properties as a structural material.

Aluminum. All of the early reactors and many of the present ones have used aluminum as their principal structural material. Although the choice of this metal usually was dictated by the demands of low absorption cross section and good aqueous-corrosion resistance at moderately low temperatures, numerous subsequent tests have shown that selection of aluminum was wise from the radiation-damage point of view as well. Radiation damage generally is slight, although some loss of ductility is observed, as shown in the table. An associated increase in yield stress also is reported (*10*).

Steels. The changes found in irradiated steels are larger, as might be expected from their higher annealing temperatures. Typical losses in ductility are shown in the table. The EBR-1 reactor, with its high fast flux, has been used to obtain information on radiation damage to Type-347 stainless steel with fast-neutron exposures up to 4.3×10^{20} n/cm² (*11*). As shown by Fig. 3, the rates of increase in tensile strength and hardness of annealed material steadily decrease with increasing exposure, but saturation was not achieved. The original tensile strength and hardness were 130,000 psi and 48 Rockwell A. These specimens were exposed at temperatures in the range of 225–315° C. Similar changes occur in steels irradiated at 80° C (*12*).

Austenitic stainless steel shows a slight tendency to transform to ferrite (*13, 14*). One group of investigators states that it seems unlikely that the changes are large enough to affect the stainless quality of the alloys (*14*).

Carbon steels of the type used for pressure-vessel construction also show hardening and loss of ductility (*12–15*). An additional disturbing observation is the increase in temperature of the ductile-to-brittle fracture as shown in Fig. 4. The implications of this are discussed in ref. *15*, in which it is stated, "It appears possible to irradiate a steel (A-212 for instance) only sufficiently to keep the properties within the ASME Boiler Code materials specifications and yet have the impact properties shifted to an extent that may endanger service performance."

Zirconium. Another structural

Ductilities Before and After Irradiation*

Material	*Elongation at breakage (%)*	
	Before	*After*
280 aluminum	38	21
28H14 aluminum	22	20
Normalized carbon steel	22	5
Austenitic stainless steel	49	25
QMV beryllium	1.4	0.2
356 aluminum	2.7	0.6
Molybdenum	44	0

* From ref. 15.

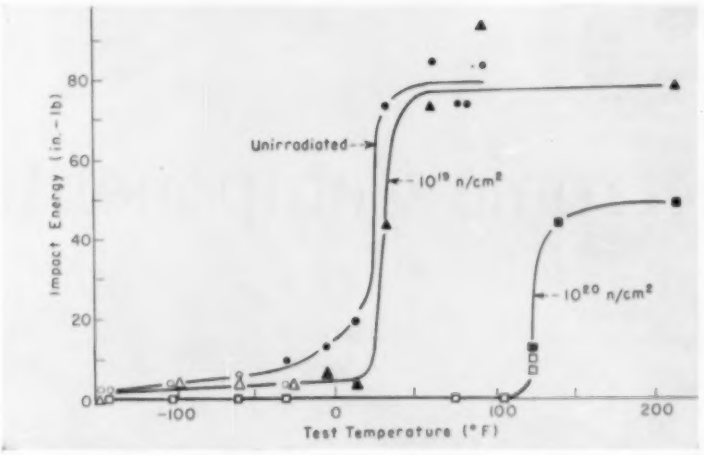


FIG. 4. Impact energy absorbed by normalized ASTM A-212 grade-B steel in breaking impact as a function of temperature. Temperature of ductile-to-brittle fracture (break in curve) increases with increasing irradiation (*15*)

metal that has been studied extensively after irradiation is zirconium (*12, 16*). The metal has been studied in the annealed state and with various degrees of cold work. Experiments with arc-melted Bureau of Mines sponge zirconium and crystal-bar material show that hardness changes are greatest in annealed material and are progressively less with increasing levels of cold work. The greater changes are found in the sponge zirconium (*16*). Zirconium appears to recrystallize and exhibit grain growth under irradiation at temperatures not exceeding 250° C (*12*).

Control Materials

Only a limited amount of information has been published on the effects of radiation on control materials. Hafnium shows changes in its mechanical properties. Boron shows extensive damage. Cadmium shows none.

Hafnium. Hafnium, which is receiving increasing use for control rods, has been found by Westinghouse investigators to show a 9.6% increase in electrical resistivity after three months' reactor exposure, hardness increases up to 12 DPH (diamond pyramid hardness) numbers, and density decreases up to 0.25%. No significant dimensional changes are found.

Boron. Boron carbide, on the other hand, is badly damaged by radiation (*17*); 16.6% burnup of the B^{10} caused extensive cracking. B_4C control rods appear to have been principally used in the USSR, but no details are available on their construction (*18*).

Preliminary data on extruded stainless steel containing up to 5% boron, irradiated to average total atom burnups up to 1.2%, show no appreciable change in dimensions, although the specimens were highly embrittled (*19*).

Cadmium. Clad plates of silver containing 25% cadmium have been irradiated for periods up to a year. Densities and dimensions show negligible changes.

Shielding Materials

For shielding purposes investigators have studied principally concrete, iron, and boral. The effects in iron are those already discussed as occurring in carbon steels. Conflicting reports have been issued concerning concrete, and boral is relatively unaffected.

Concrete. The most widely used solid shielding material for nuclear reactors has been concrete. Effects of irradiation on this material at the exposure levels prevailing in external biological shields have not been significant (*20*). Some gas, mainly hydrogen, evolves under neutron irradiation. Reports differ on the effect of radiation on mechanical properties. Some experiments indicate a *decrease* up to 30% in crushing strength while others show an even larger *increase*. Several experiments have shown decreases up to 20% in the thermal conductivity.

Boral. An aluminum-boron carbide sheet material, boral, is uniquely suited for shielding where production of hard gamma rays must be avoided (*21*). Irradiation of this material to 0.9×10^{20} n/cm² has caused no change in its strength (*22*).

Attention in this article is limited to materials of greatest current interest. Untried reactor materials always should be irradiation tested. Experimenters conducting such tests should include with their specimens suitable fast-flux monitors so that the integrated fast-neutron exposure can be measured and reported. One of the difficulties in comparing and evaluating present results is that many neutron exposures are reported in terms of thermal-neutron exposure, or simply by the length of exposure in a reactor.

* * *

This paper is based on work done under the auspices of the AEC.

BIBLIOGRAPHY

1. S. H. Paine, J. H. Kittel in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 445 (United Nations, New York, 1956)
2. S. F. Pugh, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 441 (United Nations, New York, 1956)
3. S. T. Konobeevsky, N. F. Pravdyuk, V. I. Kutaitsev, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 433 (United Nations, New York, 1956)
4. W. K. Woods, L. P. Bupp, J. F. Fletcher, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 455 (United Nations, New York, 1956)
5. John R. Huffman, NUCLEONICS, **13,** No. 4, 21 (1954)
6. R. L. Carter, W. J. Greening, Evolution of gas from graphite moderator material. Preprint 319, Nuclear Engineering and Science Congress (1955)
7. W. E. Parking, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 3, p. 295 (United Nations, New York, 1956)
8. F. E. Faris, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 484 (United Nations, New York, 1956)
9. F. Daniels, NUCLEONICS **14,** No. 3, 34 (1956)
10. D. S. Billington, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 421 (United Nations, New York, 1956)
11. W. F. Murphy, S. H. Paine, Fast neutron effects on tensile and hardness properties of stainless steel. (American Society for Testing Metals—Atomic Industrial Forum Symposium on Radiation Effects on Materials, Los Angeles, Sept. 1956)
12. S. T. Konobeevsky, N. F. Pravdyuk, V. I. Kutaitsev, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 479 (United Nations, New York, 1956)
13. M. B. Reynolds, J. R. Low, Jr., L. O. Sullivan, *J. Metals,* **7,** 555 (1955)
14. C. R. Sutton, D. O. Leeser, NUCLEONICS **12,** No. 9, 8 (1954)
15. J. C. Wilson, D. S. Billington, *J. Metals,* **8,** 665 (1956)
16. R. S. Kemper, Jr., W. S. Kelley, The effect of irradiation on the mechanical properties of arc-melted Bureau of Mines zirconium with various degrees of cold work. HW-38079 (1955)
17. W. D. Valovage, Effect of irradiation on hot-pressed boron carbide. KAPL-1403 (1955)
18. H. S. Isbin, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 3, p. 374 (1955)
19. J. D. Eichenberg, Westinghouse Atomic Power Division, personal communication (1956)
20. H. S. Davis, NUCLEONICS **13,** No. 6, 60 (1955)
21. V. L. McKinney *et al.* Boral; A new thermal neutron shield. AECD-3625 (1954)
22. A. S. Kitzes, Oak Ridge National Laboratory, personal communication (1956)

DAMAGING EFFECTS OF RADIATION...

On Electronic Components

By R. D. SHELTON and J. G. KENNEY
Admiral Corporation, Chicago, Illinois

AN EXPERIMENTAL approach to learning the effects of nuclear radiation on electrical systems can be divided into studies of materials, components, and systems. Opinions vary on the relative merits of the three approaches, but there is agreement that materials testing can be of great value in predicting the manner in which a component will fail, component testing will permit design and fabrication of a system with reasonable survival potential, and only a systems test can provide assurance that system will function.

Components testing has not been nearly as extensive as materials testing, and systems testing, because of greater complexity and lack of appropriate irradiation facilities, is practically nonexistent (*1–3*). This article is concerned with components testing.

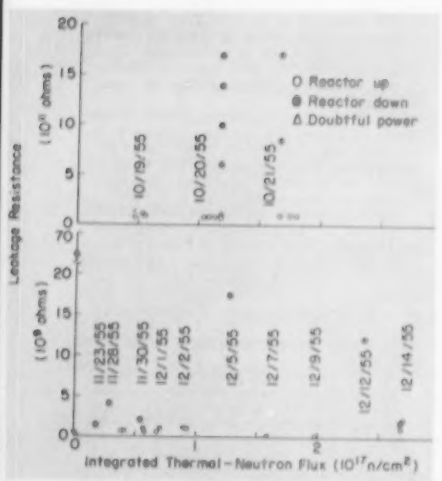


FIG. 1. Two series of observations of insulation resistance under influence of reactor radiation. Top chart shows resistance between aluminum drum and 14 ft of wire insulated with $\frac{1}{32}$-in. polyethylene. Bottom shows similar experiment with polyvinylchloride-insulated wire. Thermal neutron flux was 6 × 10¹¹ n/cm²/sec

Rate and Integral Effects

Deleterious effects can be divided roughly into two categories. Some occur immediately when the system is placed in the radiation field and are sensitive functions of radiation flux density; these are called rate effects. Long-term degenerative effects associated with the total irradiation (the time integrals of the fluxes) are called integral effects. The damage to a given component will depend on the mode of operation during irradiation, the materials comprising the component, the spectrum of the nuclear radiation, the intensity and duration of the irradiation, and other environmental factors such as temperature and humidity.

In-Pile Tests

Under an Air Force contract, our company is investigating the effects of nuclear radiation on electronic components. From July of 1955 to July of 1956 a variety of components have been irradiated in the CP-5 reactor of Argonne National Laboratory. Components were tested for performance before, during, and after irradiation, and were withdrawn from the reactor after being subjected to an integrated thermal flux of 10^{18} n/cm². Associated gamma and fast-neutron fluxes varied with position in the reactor, but typical values were 5×10^{13} fast neutrons/cm² and 10^{18} gammas/cm².

Standard military specifications were used as the guide in determining what tests should be performed. Components to be irradiated were given preirradiation tests at the Admiral Radiation Laboratory and then transported to the reactor for in-pile testing. As a rule 18 components of a given type, but perhaps of different manufacturers, comprised a test. Six components were under active test and operating during irradiation; six were irradiated but not operated; six were not irradiated and served as a control group.

Pre-irradiation testing was conducted at room temperatures, whereas in-pile testing was conducted at 50° C or above, depending on the amount of cooling and on the heat dissipated by the components being tested. The reactor environment chosen for a particular test was dictated somewhat by component size and availability of reactor space. Variations of reactor power were frequent enough to demonstrate the effect of different flux levels on component behavior.

This article discusses the effects observed so far in conductors and insulators, resistors, capacitors, semiconductors, and vacuum tubes.

Conductors and Insulators

Conductors are usually metals, which are relatively resistant to radiation damage, and insulators and dielectrics are chemical compounds with far less radiation resistance. A large volume of materials research has been accomplished in the past few years and components manufacturers are becoming aware of the problems engendered by adding nuclear radiation to the environment (*4–7*).

There are several ways in which wires and cables can be affected by nuclear radiation. The entire space in a radiation field can be thought of as an ionization chamber with charges migrating wherever there are potential differences. Beta activity produced by neutron absorption may produce "nuclear batteries" on a small scale, and

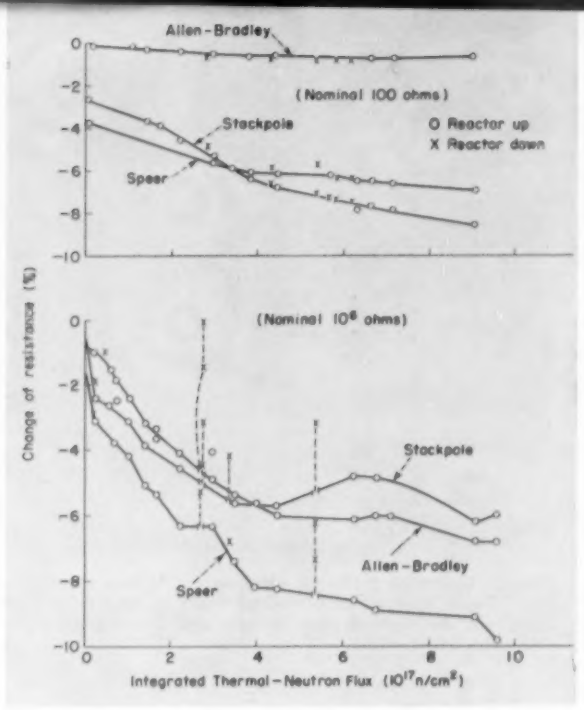


FIG. 2. Effect of in-pile irradiation on JAN RC-20-type carbon composition resistors having nominal resistances of 100 and 10^6 ohms. Recovery during reactor down time is indicated for the high-resistance elements. Irradiations were with fluxes of 9.6 $\times$ 10^{12} thermal neutrons/cm²/sec, 10^9 fast neutrons/cm²/sec, and 2 $\times$ 10^{12} gammas/cm²/sec

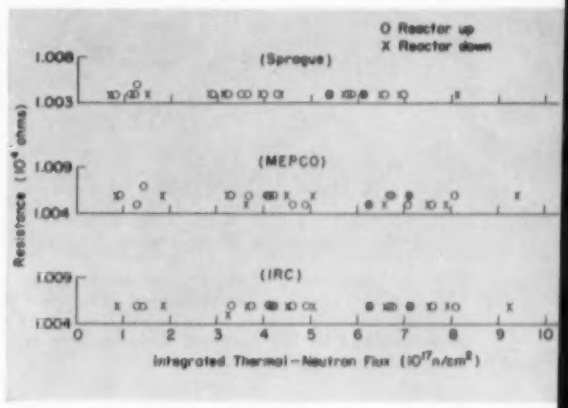


FIG. 3. Graphs demonstrate relative stability of wire-wound resistors to pile irradiation. Each point represents the average value for four resistors of nominal 10,000-ohm value. Thermal flux 6.23 $\times$ 10^{11} n/cm²/sec

large potential gradients may be produced by charge displacement through Compton collisions (*3, 8, 9*).

Figure 1 shows insulation resistance during irradiation.

Resistors

Resistors may suffer for a variety of reasons: The alternate paths afforded by ionization may reduce the effective value of large resistances subjected to high potentials. The breakdown of bonding and impregnating materials may also permit parallel conduction paths. The basic resistance material may also suffer.

Figures 2 and 3 exhibit some in-pile data on resistors. It is immediately apparent that the resistance of a component to nuclear radiation varies markedly with the manufacturer. The increase of the "rate effect" with large resistance values is expected. The initial change of resistance on insertion into the reactor results from a temperature change from 20 to 50° C. Wire-wound power resistors showed practically no radiation damage.

Capacitors

Mica, ceramic, electrolytic, and oil capacitors were tested. Electrolytic capacitors failed in about one-tenth of the standard exposure time (10^{18} n/cm²); oil capacitors enlarged due to gas evolution and developed leaks; and mica and ceramic capacitors showed

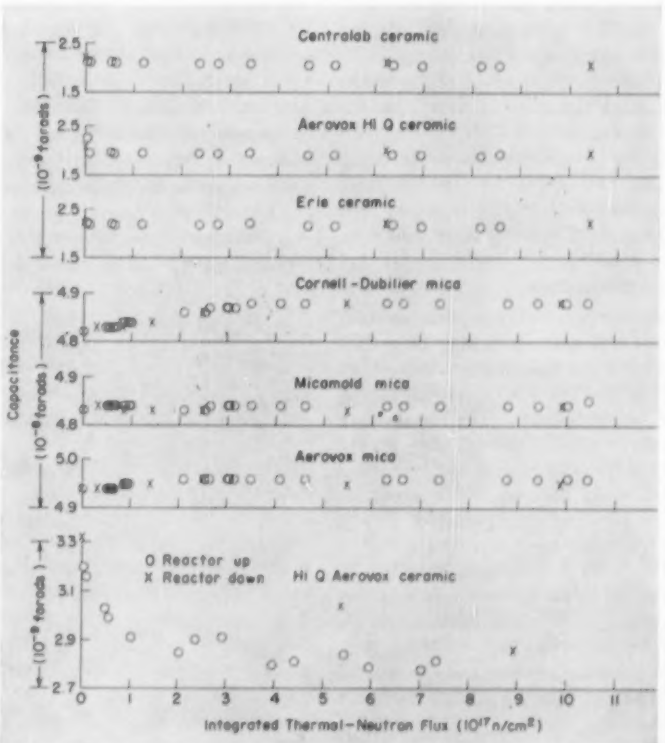


FIG. 4. Mica and ceramic capacitors show different stability under reactor irradiation. Top three charts are for CK60Y821Z ceramics. Next three are for CM61C473J micas. Bottom chart is for CK61Y152Z ceramics. Each point is an average for four capacitors. Thermal fluxes were 7 $\times$ 10^{11} n/cm²/sec for first three charts, 6 $\times$ 10^{11} n/cm²/sec for others

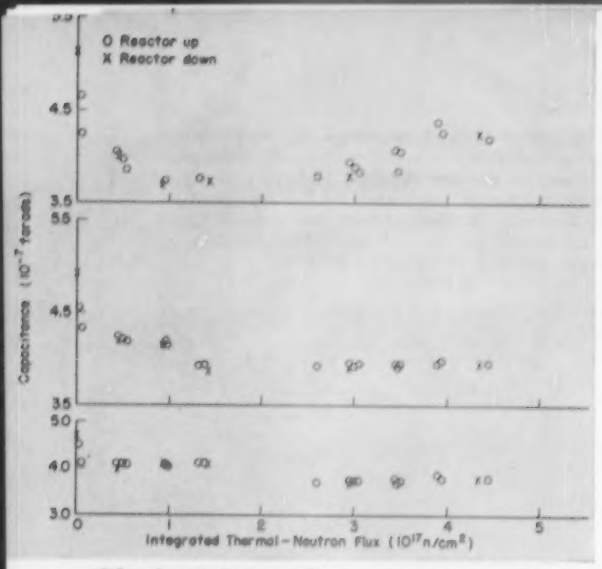


FIG. 5. Radiation effect on capacitances of type CP53B2EF504K fixed paper capacitors. Top chart shows averages for three Sprague, three Cornell-Dubilier. Center shows average for two Aerovox; bottom for one Aerovox. Thermal flux was 6.35×10^{11}

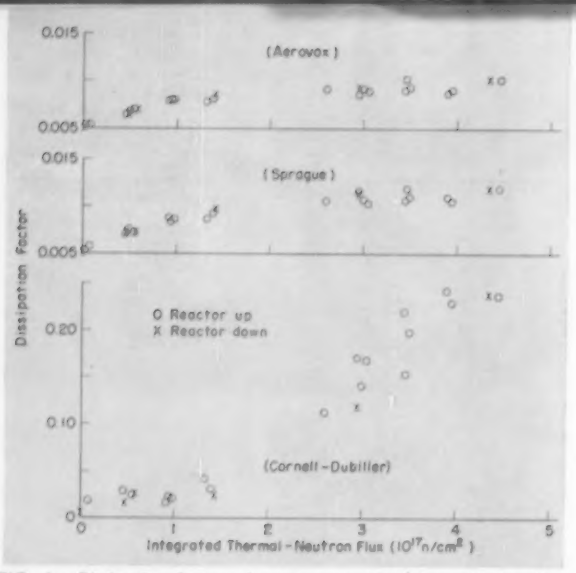


FIG. 6. Dissipation factor of paper capacitors rises with irradiation. Charts show effect of reactor fluxes (thermal 6.34×10^{11} n/cm²/sec) on Aerovox and Sprague and Cornell-Dubilier type CP53B2EF504K

little change. The results of several experiments are shown in Figs. 4–6.

Some ceramic capacitors showed sporadic capacitance charges attributed to reactor-temperature changes in the interval from 20–50° C. Other capacitors have much smaller temperature coefficients and are only slightly affected by the same temperature changes.

Measurement of small capacitances in a reactor is made difficult by the capacitance contributed by the connecting cables, which changes throughout the irradiation, and by increased dissipation factors, which make impedance measurements more difficult.

Semiconductors

Because of both the growing application of transistors and their great susceptibility to radiation damage, they have been studied as thoroughly as any type of component. The low damage threshold also has meant that weaker sources (thus more potential investigations) could be used in the study.

The effect of solar radiation on p–n junctions has been reported (*10, 11*), and gamma radiation is expected to behave in a like manner. In addition the regular structure of the crystals will be disturbed by collisions, and donors and acceptors will be created by neutron capture and subsequent beta decay.

The effect of nuclear radiation on the forward and backward current of semiconductor rectifiers, as indicated to date by this program is indicated in Fig. 7 and the table. The 1N58 germanium rectifiers supplied by Sylvania and CBS Hytron suffered drastic changes in forward and backward current characteristics before reaching an integrated thermal flux of 10^{17} n/cm². The silicon rectifiers suffered similar damage except for two manufactured by Microwave and one manufactured by Bomac. These three remained in operation during the entire test. Their successful operation indicates that semiconductor rectifiers can be developed (or present-type modified) for more severe radiation environment.

Vacuum Tubes

Vacuum tubes vary greatly in materials, size, complexity, and resistance to radiation. The most common causes of failure appear to be the deterioration of the glass envelope with subsequent gas problems, and cathode deterioration, sometimes associated with the presence of gas in the tube. More evidence is needed before a positive statement can be made, but it appears that the principal problem is to keep gas from inside the tubes.

Several tube types survived an irradi-

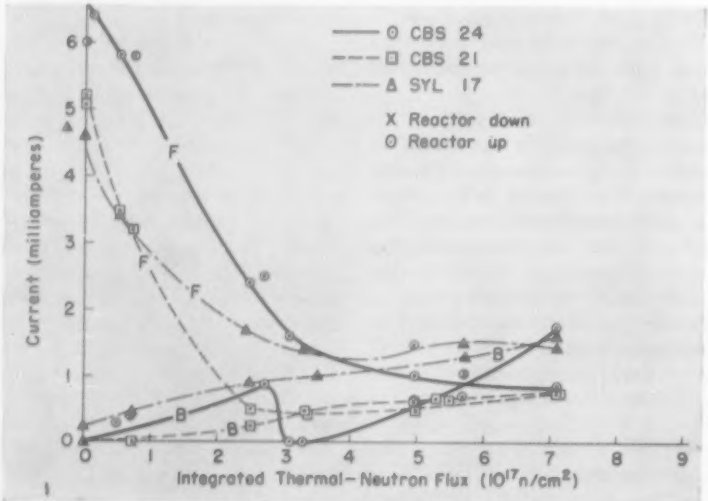


FIG. 7. Germanium rectifiers show this response to reactor radiation. Curves are for two CBS and one Sylvania crystal of type 1N58. Forward currents, shown by curves labeled "F," were measured with applied potential of 1 volt; backward currents with potential of 10 volts. Thermal-neutron flux was 0.3×10^{12} n/cm²/sec. One other Sylvania crystal was considered destroyed at 3.05×10^{17} n/cm² when its backward current rose above 5 ma

Forward and Backward Currents of 1N21 Silicon Rectifiers under Reactor Irradiation*

Date and time	Reactor up or down	Integrated thermal flux (10^{17} n/cm²)	Bomac Unit 1 F (ma)	Bomac Unit 1 B (μa)	Bomac Unit 2 F (ma)	Bomac Unit 2 B (μa)	Microwave Unit 3 F (ma)	Microwave Unit 3 B (μa)	Microwave Unit 4 F (ma)	Microwave Unit 4 B (μa)	Sylvania Unit 5 F (ma)	Sylvania Unit 5 B (μa)	Sylvania Unit 6 F (ma)	Sylvania Unit 6 B (μa)	Kentron Unit 7 F (ma)	Kentron Unit 7 B (μa)	Kentron Unit 8 F (ma)	Kentron Unit 8 B (μa)
1/3/56																		
9:45	d	0	42	120	32	115	38	400	38	200	16	2,200	39	13	44	86	32	210
10:30	u	0.014	44	105	35	107	38	380	37	200	19	2,300	40	14	44	21.5	32	180
10:45	d	0.019	17	390	35	110	38	540	37	165	19	2,600	40	18.5	44	20.5	32	380
11:30	d	0.036	15.5	390	33	110	40	415	38	175	205	3,000	40	18	45	23.5	32	360
12:30	d	0.045	17.7	380	37	105	39	600	38	175	23	3,300	40	16.3	45	21.5	33	360
1:30	u	0.061	12	380	36	140	38	500	37	200	26	3,700	40	21	45	27	33	390
2:50	u	0.090	17.5	300	36	135	39	600	38	170	26	4,800	40	26	46	30	33	390
3:45	d	0.120	17.5	610	37	140	40	590	38	180	29	4,700	38	25	135	26	27	380
1/4/56																		
8:40	u	0.416	17.5	610	35	137	37	875	38	197	31	9,000	33	215	125	34	400	1.1
10:15	u	0.450	14	975	38	137	33	620	24	290	35	8,000	35	8,500	125	40,000	450,000	400,000
11:25	u	0.475	14	7,800	38	140	37	620	38	300	28	5,800	38	7,400	125	45,000	480,000	480,000
2:00	u	0.531		**	38	340	39	620	39	300		**		**		**		**
3:00	u	0.552			36	310	38	620	38	295								
4:00	u	0.574			35	300	37	600	37	295								
1/5/56																		
8:40	d	0.868			35	280	36	560	37	250								
10:00	u	0.872			31	280	32	660	33	320								
11:00	u	0.893			30	290	31	560	32	260								
12:00	u	0.915			32	280	32	640	32	240								
1:00	u	0.936			33	290	36	660	37	235								
2:00	u	0.958			35	300	37	580	37	280								
3:00	u	0.980			36	300	37	660	38	280								
4:00	d	1.001			36	300	37	590	38	230								

* 1 volt applied for both forward and backward currents. ** At backward current > 5 ma, rectifier was considered destroyed.

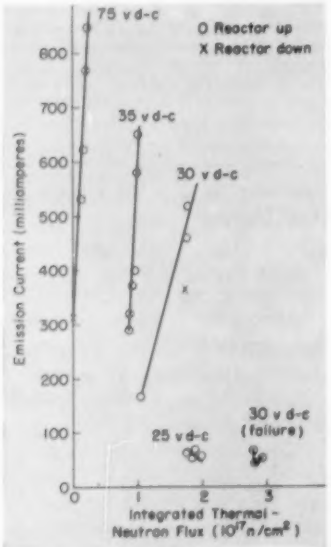


FIG. 8. Curves of emission current vs integral thermal flux demonstrate failure of 5R4WGB tubes. At failure, plate current decreased with either increase or decrease of plate voltage from 30 volts d-c. Points represent averages for 6 tubes

ation to 10^{18} n/cm² with little or no apparent damage. Some examples are cathode-ray tubes 3JP1, 3JP7, and 3JP12; gaseous voltage regulators 0A2WA, 0B2WA, and 5651; pentagrid converter 6BE6; twin diodes 6AL5 and 6080; and subminiature types 5718, 5896, and 6C4.

Other tubes failed rapidly. Examples are a beam-power 829-B, which failed before 10^{17} n/cm²; orthicons and vidicons, which suffered glass damage below 10^{17} n/cm²; rectifiers 5R4WGB, four of six failing before 4×10^{17} n/cm². Figure 8 shows the behavior of the 5R4WGB rectifiers before failure. Metal-enclosed tubes are under test.

The radiation resistance of a given component type varies widely from manufacturer to manufacturer, and there is hope that only minor changes in materials and design will greatly improve many components. Tests on resistors, semiconductor devices, and vacuum tubes support this view.

The gas problem in vacuum tubes can be solved by studying seals and glasses. Some of the tubes that failed most rapidly contained boron in the glass.

It is unfortunate that most component manufacturers regard their formulas as private data, and it is difficult to determine what materials and processes cause trouble.

* * *

The data quoted above resulted from the efforts of the radiation-effects group of Admiral Corporation; program director is E. R. Pfaff.

BIBLIOGRAPHY

1. E. R. Pfaff, R. D. Shelton, The effects of nuclear radiation on electronic components. Admiral Corporation (1955, '56)
2. Nucleonics **14,** No. 7, 33 (1956)
3. C. C. Robinson, *American Aviation,* **19,** No. 26, 53 (1956)
4. A. E. Javitz, *Electrical Manufacturing,* **55,** No. 6, 85 (1955)
5. Effects of radiation on dielectric materials, ONR Symposium Report ACR-2. (December, 1954)
6. O. Sisman, C. Bopp, Physical properties of irradiated plastics. ORNL-928
7. R. D. Shelton, The problem of electronic components in nuclear power plants. Aeronautical Electronics Conference Proceedings, Dayton, Ohio (1956)
8. A. Thomas, Nucleonics **13,** No. 11, 129 (1955)
9. J. R. Milliron, *Electrical Manufacturing* **56,** No. 5, 125 (1955)
10. H. Thanos, R. Weber, Investigation of solar cells. Admiral Report (August 5, 1955)
11. Bell Telephone Laboratories advertisement, *Electronics* **29,** No. 1, 78 (1956)

DAMAGING EFFECTS OF RADIATION...

On Plastics and Elastomers

By ROBERT HARRINGTON
Hanford Atomic Products Operation
General Electric Company
Richland, Washington

STUDY OF HOW radiation affects solid materials incorporated in various components of a reactor is necessary because of the changes induced. The design engineer is confronted with new materials selection problems.

The solid constructional materials most susceptible to change under radiation bombardment are the molecular solids to which the plastics and elastomers or rubber-like materials belong.

Radiation Source

As it is believed that the changes induced in organic materials are essentially the same for any type of ionizing radiation with respect to energy absorbed, gamma radiations from spent fuel elements and cobalt-60 isotope sources were used as being representative of ionizing radiations in general. However, it may be possible that this relationship is not valid over a wide range of energy absorption levels and rates.

Effects of irradiation rates are shown in Table 1. These imply that materials in a radiation field of a few hundred r/hr would not be altered as much at any given total dose as they would be at the dose rates used here.

Procedure and Results

The experimental work was designed primarily as a screening process whereby promising materials could be selected for more comprehensive study as dictated by specific applications. However, in some instances sufficient data were obtained for design purposes.

Ultimate elongation and tensile strength properties were measured in accordance with ASTM D 412-51T using three Die C specimens for each exposure. A 180-deg bend test was also made after the exposures by folding the broken tensile specimen back on itself with positive finger pressure applied to insure the specimen sides were in contact. Hardness and elasticity measurements were not taken for the more rigid ethylene materials. Properties were measured at 25° C and 50% relative humidity after a 1-hr conditioning period.

Table 2 summarizes the changes in properties of plastics and elastomers induced by various doses of gamma radiation from spent fuel elements.

Discussion

The data show how plastics and elastomers degrade* from exposure to gamma (ionizing) radiation. In many instances, short doses will actually improve the properties of the materials, but with continued exposure severe property changes occur and the materials are altered radically.

Properties. The elongation appears to be the most sensitive property measured and provides a fairly good index of the degradation of the material. However, the flexibility probably offers, for the longer exposures, a better means of determining the condition of the material. This is illustrated by comparing the two silicone rubbers SE-361

* "Degrade" as used here denotes a reduction in the usefulness of a material as a result of its properties being changed by exposure to an environment. Degrade often denotes the decrease in molecular weight of a material from exposure to an environment.

TABLE 1—How Polymer Properties are Changed by 5×10^7 r from Co^{60} Compared with the Same Dose from Spent Fuel Elements*

	Percent change in properties				
Material and source	*Hardness*	*Elasticity*	*Elongation*	*Tensile*	*Weight*
Silastic 152					
Cobalt-60	46.0	−51.8	−77.3	3.7	−0.09
Spent fuel elements	36.0	−40.7	−68.2	−8.8	−0.13
Alathon 4BK20					
Cobalt-60	—	—	−84.3	−10.8	0.17
Spent fuel elements	—	—	−59.0	−19.7	0.29
SE-361					
Cobalt-60	6.7	−60.0	−48.4	16.3	0.14
Spent fuel elements	1.3	−40.0	−38.5	7.0	0.20
Hycar 1001					
Cobalt-60	5.3	−7.7	−74.6	−16.7	0.17
Spent fuel elements	1.3	−15.4	−68.2	−14.4	0.07

* Incident rates: $Co^{60} \approx 3.7 \times 10^5$ r/hr in 25° C air; spent fuel elements $\approx 10^5$ r/hr in 15° C air.

and SE-550. The properties of these materials undergo very nearly the same changes, but at any given radiation dose, the SE-550 is much more flexible and appears in better over-all condition.

Weight and thickness measurements do not indicate the condition of a material. Teflon at an exposure of 5×10^6 r had not changed in either weight or thickness but was extremely brittle and crumbly.

Elasticity appears to offer the same advantages as does elongation. However, because of the scale used (0 to 100), materials having an initial elasticity of 6, which lowers to 3 after exposure, have essentially undergone less change than those materials that change from 30 to 15—the over-all change being a 50% reduction in elasticity. Also, in the first case because of the low values, a larger error is introduced because of the measurement method.

Materials. The styrene rubber PR 408-70 is affected less than the other materials investigated. This is due to the presence of the styrene, which is able to absorb greater amounts of energy from radiation without being altered to the same degree as the other materials. The acrylics, neoprenes, and nitrile classes all appear to be about equally damaged.

Teflon is the poorest of all the materials evaluated. It is severely damaged at 5×10^6 r. Kel-F elastomer and Hycar 2202 (butyl type) both softened and became tacky, indicating poor suitability in radiation fields.

The remainder of the ethylene materials appear to be in the same class as the acrylics, neoprenes, and nitriles on the basis of the longer exposures. However, intermediate doses affected the ethylenes in a different manner; properties were either upgraded or degraded depending upon the amount of exposure received.

The vinyls appear to sustain less damage than all other materials except the styrene-type rubber. The silicone elastomers as a class are inferior to all other classes except the fluorocarbons and butyl. However, within the silicone class, the phenyl types are superior to the methyl and vinyl types owing to the presence of the benzene ring.

Data presented for all exposures at 5×10^6 r show conclusively that most materials are significantly affected by this dose, and shorter exposures are needed before the complete representation of property changes can be shown.

TABLE 2—How Gamma Radiation Affects Properties of Plastics and Elastomers

Material and recipe	Radiation exposure (10^6r)	Initial properties and percent change: Hardness (Shore A; Δ%)	Elasticity (Shore; Δ%)	Elongation (%; Δ%)	Tensile (psi; Δ%)	Weight (Δ%)
ACRYLICS						
Acrylon BA-12, black, copolymer of an acrylic ester and acrylonitrile, Borden Co.						
Acrylon BA-12, 100.0; Stearic acid, 1.0; sulfur, 1.0; triethylene tetramine, 2.0; SRF black, 50.0. Cured 30 min at 310° F	0	32	15	285	1,700	—
	5	4 8	13 3	−12 0	14 1	−0 12
	10	−4 8	−13 3	−3 2	7 2	−1 16
	50	0 0	−20 0	−33 1	2 5	0 08
	100	−1 2	−46 7	−47 2	−5 3	0 60
	150	0 0	−46 6	−41 9	10 4	0 12
Acrylon EA-5, black, copolymer of an acrylic ester and acrylonitrile, Borden Co.						
Acrylon EA-5, 100.0; stearic acid, 1.0; sulfur, 1.0; triethylene tetramine, 1.0; SRF black, 80.0. Cured 30 min at 310° F	0	84	15	435	1,885	—
	5	−1 2	80 0	−24 0	−7 4	−0 20
	10	−4 8	66 7	−21 7	−0 9	0 0
	50	−8 3	0 0	−41 2	−10 2	0 0
	100	−9 5	−13 3	−56 2	−18 9	0 55
	150	−4 8	−40 0	−63 1	−25 1	0 13
Vyram, black, acrylate, Monsanto Chemical Co.						
Vyram, 100.0; CC black, 30.0; silica, 10.0; oleic acid, 1.0; stearic acid, 3.0; magnesium oxide, 10.0; dicumyl benzene, 3.0; dicumyl peroxide, 3.0. Cured 30 min at 330° F	0	68	32	275	970	—
	5	−5 3	0 0	−27 0	10 2	0 01
	10	−5 8	−31 2	−34 3	40 1	0 04
	50	16 2	−68 8	−72 6	12 6	0 05
	100*	26 5	−68 7	−83 6	−11 7	1 50
	150*	33 8	−71 9	−87 2	−0 72	0 51

Material and recipe	Radiation exposure (10^6r)	Initial properties and percent change: Hardness (Shore A; Δ%)	Elasticity (Shore; Δ%)	Elongation (%; Δ%)	Tensile (psi; Δ%)	Weight (Δ%)
Hycar 4021, black, ethyl acrylate and chloro ethyl vinyl ether, B. F. Goodrich Chemical Co.						
Hycar 4021, 100.0; stearic acid, 1.0; Philblack A, 40.0; benzothiazol disulfide, 2.0; TETA, 1.5. Cured 30 min at 310° F; post cured 24 hr at 300° F	0	64	66	390	1,780	—
	5	−3 13	6 06	−12 4	−13 6	−0 15
	10	−3 13	−24 2	−25 3	−15 8	−0 03
	50	3 13	−24 2	−66 5	−61 8	0 50
	100	9 38	−39 9	−75 5	−64 0	0 32
	150	12 5	−69 7	−80 7	−54 8	−0 41
BUTYL						
Hycar 2202, brominated copolymer of isobutylene and isoprene, B. F. Goodrich Chemical Co.						
Hycar 2202, 100.00; stearic acid 1.00; zinc oxide, 5.00; Philblack 0, 50.00; Blackbird sulfur, 2.00; benzothiazial di sulfide, 0.25; TMTD, 0.50. Cured 30 min at 310° F; post cured 24 hr at 300° F	0	73	44	345	2,130	—
	5	−2 74	25 0	3 20	−9 20	0 28
	10†	−5 5	11 4	−8 4	−31 9	0 19
	50‡	−19 2	−43 2	−12 8	−79 3	0 44
	100‡	−20 5	−68 2	−27 3	−87 8	0 97
	150‡‡‡	−38 4	−84 1	−12 8	−100	0 20
ETHYLENES						
Agilene, white, polyethylene (low-density type—no. avg. mol. wt. = 22–24,000), American Agile Corp.						
No additives	0	—	—	—	1,805	—
	5	—	—	13 3	17 9	0 05
	10	—	—	45 6	34 9	0 07
	50§	—	—	−52 3	−26 5	0 30
	100¶	—	—	−84 6	−14 5	0 38
	150*·§§§	—	—	−87 9	−10 7	0 56

TABLE 2—How Gamma Radiation Affects Properties of Plastics and Elastomers (*continued*)

Material and recipe	Radiation exposure ($10^6 r$)	Initial properties and percent change: Hardness (Shore A; Δ%)	Elasticity (Shore; Δ%)	Elongation (%; Δ%)	Tensile (psi; Δ%)	Weight (Δ%)
ETHYLENES (*continued*)						
Alathon 4BK-20, black, polyethylene (low-density type—no. avg. mol. wt. = 33,000), duPont Co.						
Additives: 0.07% DPPD, 2.5% channel black	0	—	—	575	2,060	—
	5	—	—	−44.1	−13.8	−0.01
	10	—	—	−17.9	46.4	0.05
	50	—	—	−59.0	−19.7	0.29
	100	—	—	−85.2	−2.0	0.33
	150	—	—	−83.4	1.6	0.32
Alathon 5BK-22, black, polyethylene (low-density type—no. avg. mol. wt. = 20,000), duPont Co.						
Additives: 0.07% DPPD, 2.5% channel black	0	—	—	625	1,975	—
	5	—	—	−23.3	−4.8	0.07
	10	—	—	−19.3	9.1	0.07
	100	—	—	−88.0	6.4	0.34
	150*	—	—	−96.0	7.9	0.34
Bakelite 4401, black, polyethylene (low-density type—Bakelite DFD-4401 Black-9955), Bakelite Co.						
Additives: channel black, antioxidant	0	—	—	570	1,720	—
	5	—	—	15.3	16.1	0.07
	10	—	—	17.1	36.8	0.06
	100	—	—	−81.5	−1.98	0.38
	150*	—	—	−89.4	4.01	0.43
Syper Dylan, white, polyethylene (high-density type), Koppers Co.						
Additives: Unknown	0	—	—	20	3,435	—
	5	—	—	125.0	12.4	−0.06
	10	—	—	275.0	2.56	0.02
	50*,†	—	—	−50.0	−8.7	0.13
	100*,†	—	—	−25.0	7.8	0.13
	150*,‡	—	—	−50.0	10.0	0.17
Irrathene 101, white, polyethylene (low-density type, irradiated), General Electric Co.						
No additives	0	—	—	565	3,210	—
	5	—	—	−3.37	−5.02	0.09
	10	—	—	−11.3	−15.3	0.34
	50§	—	—	−75.2	−56.5	1.24
	100§	—	—	−91.1	−52.4	2.02
	150¶	—	—	−94.7	−49.9	2.35
Irrathene 201, off-white, polyethylene (low-density type, irradiated), General Electric Co.						
Antioxidant additives	0	—	—	610	3,295	—
	5	—	—	−5.43	1.09	0.02
	10	—	—	−3.8	−9.3	0.13
	50	—	—	−41.6	−30.5	0.88
	100§	—	—	−88.5	−53.9	1.83
	150¶	—	—	−92.6	−49.8	2.24
Irrathene 202, black, polyethylene (low-density type, irradiated), General Electric Co.						
Additives: antioxidant, carbon black	0	—	—	535	3,555	—
	5	—	—	−2.99	−20.1	0.09
	10	—	—	−4.9	−20.3	0.21
	50	—	—	−68.3	−61.4	1.20
	100	—	—	−89.7	−54.2	1.81
	150	—	—	−94.4	−48.9	2.36
NITRILES						
Hycar 1001, black, copolymer of butadiene and acrylonitrile (high acrylonitrile content), B. F. Goodrich Chemical Co.						
Hycar 1001, 100.0; zinc oxide, 5.0; Philblack A, 40.0; stearic acid, 1.0; methyl tuads, 3.5. Cured 30 min at 310° F	0	75	78	710	3,460	—
	5	−1.3	2.6	−32.9	−3.15	−1.10
	10	−4.0	−14.1	−43.5	−0.03	0.0
	50	1.3	−15.4	−68.2	−14.4	0.07
	100	9.3	−51.3	−83.1	−24.0	0.44
	150	18.7	−61.5	−85.2	−22.2	0.51
Hycar 1002, black, copolymer of butadiene and acrylonitrile (medium acrylonitrile content), B. F. Goodrich Chemical Co.						
Hycar 1002, 100.0; zinc oxide, 5.0; Philblack A, 40.0, stearic acid, 1.0; methyl tuads, 3.5. Cured 30 min at 310° F	0	71	78	435	3,000	—
	5	1.4	8.9	2.1	11.5	1.10
	10	−2.8	6.4	−7.1	8.6	0.04
	50	7.0	5.13	−34.6	−35.1	0.18
	100	15.5	−10.3	−71.3	−38.4	0.89
	150	23.9	−61.5	−78.2	−32.9	0.51
Parker 46-101, black, copolymer of butadiene and acrylonitrile (Paracril 35 copolymer used), Parker Appliance Co.						
Recipe not known; a proprietary material	0	72	65	500	2,460	—
	5	1.4	30.8	−14.7	6.1	−0.09
	10	−2.8	15.4	−16.7	−4.9	−0.03
	50	2.8	16.9	−47.8	−14.6	0.02
	100	9.3	−26.2	−69.9	−21.9	0.54
	150	16.7	−38.5	−75.9	−15.1	0.28
PR 142-70, black, copolymer of butadiene and acrylonitrile (Hycar 1002 copolymer used), Precision Rubber Products Corp.						
Recipe not known; a proprietary material	0	71	55	410	1,335	—
	5	−2.8	50.9	−13.0	6.7	−0.07
	10	−2.8	36.4	−9.3	3.4	−0.03
	50	0.0	60.0	−47.3	7.7	0.07
	100	5.6	11.8	−59.6	1.6	0.48
	150	14.1	−18.2	−71.8	6.6	0.43
PR 122-70, black, copolymer of butadiene and acrylonitrile (Hycar 1042 copolymer used), Precision Rubber Products Corp.						
Recipe not known; a proprietary material	0	75	82	255	2,075	—
	5	1.3	1.2	−5.5	6.6	−0.03
	10	−1.3	−4.9	−7.5	0.0	−0.09
	50	−1.3	0.0	−21.3	6.1	0.04
	100	2.67	−4.88	−39.0	−13.3	0.53
	150	5.33	−26.8	−54.7	−15.1	0.50
Parker 1063-16, black, copolymer of butadiene and acrylonitrile (Hycar 1002 copolymer used), Parker Appliance Co.						
Recipe not known; a proprietary material	0	66	77	455	2,630	—
	10	0.0	−3.9	−21.8	2.8	0.08
	150	22.7	−61.0	−76.9	−50.0	0.53

ETHYLENES (*continued*)

Hypalon S-2, black, chlorosulfonated polyethylene, duPont Co.

Recipe not known	0	76	38	265	1,160	—
	5	−3.9	23.7	1.88	38.4	−0.07
	10	−6.58	13.2	−5.66	20.3	−0.10
	50	−2.6	−15.8	−35.9	32.5	−0.61
	100	9.2	−36.8	−52.8	20.3	−0.15
	150	11.8	−60.5	−60.4	20.3	−0.47

Hypalon A2411A-277, black, chlorosulfonated polyethylene, duPont Co.

Hypalon 20, 100.00; stabelite resin, 2.50; NBC, 1.00; antox, 2.00; litharge, 40.00; SRF black, 30.00; MBTS, 0.50; tetrone A, 0.75. Cured 30 min at 307° F	0	81	34	245	2,790	—
	5	0.0	−5.8	−2.4	3.9	0.06
	10	0.0	−11.8	−6.5	13.5	0.07
	100	0.0	−41.2	−55.3	7.0	0.31

Teflon, off-white, polytetrafluoroethylene, duPont Co.

	0	—	—	220	2,535	—
	5*,§§	—	—	−93.2	−40.8	0.0

Kel-F elastomer, white, copolymer of chlorotrifluoroethylene and vinylidene fluoride, U. S. Rubber Co.

Recipe not known	0	75	54	640	1,100	—
	5†	−12.0	35.2	4.4	23.6	0.03
	10	−6.7	1.9	−10.4	37.4	0.06
	100¶¶	−10.8	−14.8	−75.9	−36.4	0.66

NEOPRENES

M-3854, black, polymer of chloroprene, U. S. Rubber Co.

Recipe not known; a proprietary material	0	56	80	783	1,105	—
	5	0.0	6.3	***	***	−0.15
	10	0.0	−10.0	***	***	−0.14
	50	0.0	−22.5	−25.3	−6.2	0.30
	100	10.7	−50.0	−55.9	−31.9	1.70
	150	−6.67	−52.2	−79.6	−42.8	1.86

M-3871, black, polymer of chloroprene, U. S. Rubber Co.

Recipe not known; a proprietary material	0	75	46	490	1,350	—
	5	0.0	−10.9	−15.3	3.7	−0.04
	10	−2.7	−15.2	−48.3	10.2	0.02
	50	1.3	−17.4	−38.8	−5.6	0.30
	100	6.67	−39.1	−59.2	−19.1	0.73
	150	55.4	−82.5	−80.6	5.93	1.69

A9A-35, black, polymer of chloroprene, duPont Co.

Neoprene type GN, 100.0; neozone A, 1.0; stearic acid, 0.5; SRF black, 80.0; Circo LP oil, 20.0; red lead, 20.0. Cured 30 min at 307° F	0	78	80	385	1,854	—
	5	−3.8	−7.5	21.7	11.2	−0.14
	10	1.43	0.0	−12.9	14.9	0.0
	50	−5.1	−25.0	−43.9	10.0	0.0
	100	6.4	−27.5	−75.2	−5.8	0.41
	150	14.1	−81.3	−80.4	19.3	0.45

A411A-1160, black, polymer of chloroprene, duPont Co.

Neoprene W, 100.0; Aranox, 1.0; Akroflex CD, 1.0; stearic acid, 0.5; SRF black, 75.0; Circo LP oil, 10.0; red lead, 20.0; Thionex, 1.0; sulfur, 1.0. Cured 20 min at 307° F	0	—	—	—	—	—
	5	7.1	25.0	−8.8	167.9	0.05
	10	4.3	11.7	−17.1	170.6	−0.01
	50	10.0	−5.0	−48.9	134.5	0.0
	100	20.0	−30.0	−71.0	128.9	0.59
	150	28.6	−75.0	−77.9	194.5	0.23

SILICONES

SE-361, red, silicone (methyl vinyl type), General Electric Co.

Recipe not known; a proprietary material	0	75	20	120	945	—
	5	−5.3	−10.0	10.7	1.7	0.01
	10	−1.3	−25.0	−13.9	1.3	0.07
	50	1.3	−40.0	−38.5	7.0	0.20
	100*	13.3	−65.0	−71.3	−16.8	0.20
	150*	14.7	−70.0	−67.2	1.80	0.02

SE-371, red, silicone (methyl vinyl type), General Electric Co.

Recipe not known; a proprietary material	0	78	13	90	1,020	—
	5	−2.56	−7.69	−13.0	−13.5	−0.02
	10	−2.6	−38.5	−18.5	−6.4	−0.04
	50*	6.4	−61.5	−34.8	25.2	0.11
	100*	12.8	−53.9	−54.4	19.7	0.32
	150*	16.7	−84.6	−67.4	54.9	0.17

SE-381, red, silicone (methyl vinyl type), General Electric Co.

Recipe not known; a proprietary material	0	86	12	70	975	—
	5	−5.81	−41.7	−4.76	−4.42	−0.02
	10*	−4.7	−58.3	−11.8	2.3	−0.05
	50*	1.2	−66.7	−26.5	33.9	0.15
	100*	3.49	−66.7	−41.2	44.3	0.32
	150*	8.14	−83.3	−70.6	88.3	0.28

GE 81598, translucent light tan, silicone, General Electric Co.

Recipe not known; a proprietary material	0	60	25	205	670	—
	5	5.0	−16.0	−11.8	14.6	−0.09
	10	3.3	−16.0	−21.6	7.8	0.02
	50	18.3	−44.0	−53.4	3.4	0.05
	100*	33.3	−76.0	−66.2	−89.3	0.21
	150*	46.7	−88.0	−79.9	−26.4	0.33

GE 81590, semitranslucent light tan, silicone (methyl type), General Electric Co.

Recipe not known; a proprietary material	0	58	32	285	1,090	—
	5†††	0.0	−6.25	−6.69	−10.8	0.07
	10†††	−3.5	−9.4	−12.0	−10.7	0.11
	50‡‡‡	3.4	−37.5	−50.7	−43.8	0.19
	100‡‡‡	13.9	−37.5	−64.1	−34.9	0.35
	150*,§§§§	31.0	−68.8	−78.9	−40.7	0.28

Silastic 80, white, silicone (methyl vinyl type), Dow Corning Corp.

Recipe not known; a proprietary material	0	80	4	205	690	—
	5	2.4	0.0	−12.6	13.9	0.04
	10	1.8	0.0	−40.1	9.1	−0.03
	50	4.8	0.0	−56.3	24.2	0.16
	100§	9.5	−75.0	−78.2	−85.3	0.37
	150§	11.9	−50.0	−80.5	−83.8	0.56

Silastic 50, white, silicone (methyl vinyl type), Dow Corning Corp.

Recipe not known; a proprietary material	0	68	25	255	735	—
	5	−4.4	0.0	−13.0	15.5	0.02
	10	1.5	0.0	−26.9	17.0	−0.08
	50§§§	10.3	−52.0	−54.5	36.3	0.08
	100¶¶¶	20.6	−56.0	−78.3	8.2	0.26
	150*,††††	25.0	−84.0	−82.2	−10.0	0.59

Material and recipe	Radiation exposure (10^6r)	Initial properties and percent change: Hardness (Shore A; Δ%)	Elasticity (Shore; Δ%)	Elongation (%; Δ%)	Tensile (psi; Δ%)	Weight (Δ%)
Silastic S2048, white, silicone (methyl phenyl type), Dow Corning Corp.						
Recipe not known; a proprietary material	0	64	15	320	675	—
	5	−1.6	20.7	−22.4	17.8	0.03
	10	3.1	33.3	−42.5	10.1	0.04
	50	12.5	−20.0	−56.5	28.0	0.19
	100****	23.4	−46.7	−73.6	22.7	0.25
	150*,††††	31.3	−33.3	−76.7	−85.3	0.19
Silastic 675, red, silicone (methyl phenyl type), Dow Corning Corp.						
Recipe not known; a proprietary material	0	75	5	210	700	—
	5	8.0	0.0	−15.1	4.4	0.04
	10	9.3	−40.0	−22.3	22.1	−0.10
	50	10.7	−60.0	−84.1	−9.5	0.13
	100*	20.0	−60.0	−73.0	−85.3	0.17
Silastic 152, red, silicone, Dow Corning Corp.						
Silastic 401 gum, 100.0; Dow Corning Silica, 30.0; Celite Superfloss, 19.0; iron oxide, 2.8; Luperco ASF, 1.4. Cured 5 min at 260° F	0	50	27	440	845	—
	5	4.0	−3.0	−3.4	−0.95	0.0
	10	22.0	3.7	−36.4	17.2	−0.15
	50	36.0	−40.7	−68.2	−8.8	−0.13
	100	70.0	−63.3	−87.6	−8.4	0.05
Parker 77-018, green, silicone, Parker Appliance Co.						
Recipe not known; a proprietary material	0	78	10	375	985	—
	5	−5.0	−11.1	−36.2	−26.6	0.04
	10	−2.6	−11.4	−7.8	−10.5	0.04
	100*	11.5	−55.5	−80.5	−13.5	0.46
	150*	17.9	−78.0	−87.6	−76.0	0.63
Arcosil 2184, red, silicone, Arrowhead Rubber Co.						
Recipe not known; a proprietary material	0	54	15	375	360	—
	5	7.41	−6.67	−41.0	−41.8	0.04
	10	11.1	−13.3	−50.4	61.0	−0.01
	50	31.5	−24.2	−66.5	−61.8	0.30
	100	44.4	−26.7	−83.9	−91.6	0.22
	150*	57.4	−66.7	−89.3	−97.5	0.24
Cohrlastic 500, red, silicone, Connecticut Hard Rubber Co.						
Recipe not known; a proprietary material	0	80	15	170	300	—
	5	−16.3	0.0	−3.8	−5.3	0.01
	10	−15.0	−13.3	−16.7	0.0	0.01
	50	−10.0	−20.0	−49.4	39.2	0.06
	100*	−1.3	−66.6	−73.2	30.2	0.22
	150*	6.25	−73.3	−64.3	−79.4	0.50
Cohrlastic 700, gray, silicone, Connecticut Hard Rubber Co.						
Recipe not known; a proprietary material	0	65	30	210	440	—
	5	−18.5	6.7	−10.4	41.2	−0.03
	10	−12.3	−6.6	−31.6	−12.4	−0.04
	50	0.0	−43.3	−55.2	25.1	0.12
	100*	15.4	−70.0	−71.7	26.5	0.24
	150*	26.2	−76.7	Too brittle to test		0.58
Fairprene SR-5570, gray, silicone, duPont Co.						
Recipe not known; a proprietary material	0	62	30	420	1,025	—
	5	6.5	−73.3	−31.0	5.5	0.02
	10	9.7	−66.7	−33.3	6.1	0.04
	50	25.8	−76.7	−65.5	−0.40	0.16
	100*	40.3	−86.7	−90.5	−29.1	0.46
	150*	45.2	−66.7	−91.7	−92.6	0.66
K-1035, translucent light tan, silicone, Union Carbide and Carbon Corp.						
Recipe not known; a proprietary material	0	55	45	240	740	—
	5	0.0	−11.1	−17.4	4.9	0.0
	10	7.1	−11.1	−29.8	−6.8	0.05
	50	16.1	−57.8	−48.3	−1.1	0.06
	100*	25.3	−80.0	−71.1	0.95	0.22
	150*	48.2	−86.7	−77.3	−12.0	0.30
SE-550, translucent light tan, silicone (methyl phenyl type), General Electric Co.						
Recipe not known; a proprietary material	0	63	15	210	660	—
	5	0.0	19.1	−4.3	7.6	−0.02
	10	3.2	6.6	−13.9	0.8	0.04
	50	7.9	−26.7	−44.9	−6.1	−0.04
	100††	19.0	−66.7	−66.5	−15.8	0.23
	150*,‡‡‡‡	30.2	−60.0	−79.0	−6.82	0.10
SE-551, white, silicone (methyl phenyl type), General Electric Co.						
Recipe not known; a proprietary material	0	56	35	350	1,214	—
	5	−3.6	6.9	−10.0	2.6	0.03
	10	5.4	11.4	−14.3	−3.8	0.09
	50	16.1	−60.0	−52.9	−9.9	0.08
	100§	35.7	−71.4	−78.6	−41.4	0.33
STYRENES						
PR 408-70, black, copolymer of styrene and acrylonitrile (GR-S-1000 copolymer used), Precision Rubber Products Corp.						
Recipe not known; a proprietary material	0	74	55	230	1,790	—
	5	1.3	12.7	−1.3	−4.7	0.0
	10	1.4	0.0	7.5	7.0	0.01
	50	−1.4	1.8	−12.3	6.4	0.08
	100	0.0	−3.6	−21.1	−2.0	0.61
	150	5.41	−14.6	−36.4	−10.2	0.46
VINYLS						
Vyflex White, white, polyvinyl chloride (plasticized, Vyflex L-10 White), Kaykor Industries, Inc.						
Recipe not known; a proprietary material	0	92	6	310	2,590	—
	5	3.3	0.0	36.4	13.7	0.06
	10	3.3	−16.7	29.5	14.6	0.07
	50	0.0	−66.7	2.3	−1.4	0.20
	100	−1.1	16.7	−6.8	−7.8	1.2
	150	−1.1	−33.3	−43.6	−19.6	0.77
Vyflex Black, black, polyvinyl chloride (plasticized, Vyflex L-10 Black), Kaykor Industries, Inc.						
Recipe not known; a proprietary material	0	91	5	310	2,900	—
	5	5.5	0.0	−2.73	2.8	0.0
	10	4.4	−60.0	−1.0	6.9	0.05
	50	3.3	−60.0	−2.7	−7.7	0.20
	100	3.3	−20.0	−28.3	−5.3	1.4
	150	4.4	−40.0	−48.4	−24.6	1.00

* Samples exposed to this extent broke when subjected to the flexibility test. † Specimen became slightly tacky. ‡ Tackiness increased. § Turned slightly yellow. ¶ Turned slightly darker yellow. †† Turned amber. ‡‡ Dark tan, quite brittle. §§ Very brittle and crumbly. ** More tacky. ¶¶ Flow-like marks on surface. *** Did not break at 900% elongation. ††† Turned to greenish color. ‡‡‡ Darker green. §§§ Turned slightly grayish. ¶¶¶ Light bluish-gray. **** Turned to grayish color. †††† Yellowish-gray. ‡‡‡‡ No strength; very tacky and gummy. §§§§ Dark yellow. ¶¶¶¶ Very dark green. ††††† Gray. ‡‡‡‡‡ Very amber.

DAMAGING EFFECTS OF RADIATION . . .

On Chemical Materials

By J. C. BRESEE, J. R. FLANARY, J. H. GOODE, C. D. WATSON, and J. S. WATSON
Chemical Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

IMPORTANT IN THE REPROCESSING of reactor fuels is the effect of radiation damage on process reagents and organic materials of construction, especially for short-cooled fuels where the fission-product radiation is very intense. The magnitude of the chemical and physical changes produced by radiation is sufficient to affect the usefulness, and even the feasibility, of some materials used in the recovery of uranium, thorium, and other materials from irradiated reactor fuels. This article presents the details of how gamma radiation damages organic protective coatings and gaskets.

To simulate fission-product radiation, a cobalt-60 gamma source was used for these tests. Average gamma energy is 1.2 Mev. The source provided an intensity of $1.2\text{–}3.6 \times 10^4$ r per minute in air; the maximum of total radiation accumulated by the test specimens was about 10^9 r.

The specimens. Radiation stability of many industrial materials has been tested on a laboratory scale to aid in selecting materials for the construction and operation of radiochemical processing plants. The materials were acquired by: (a) accepting samples from vendors who solicited ORNL, and (b) nonexhaustive queries to vendors whose products appeared to be of interest.

Materials that apparently exhibit poor radiation stability in these tests need not be considered inferior products; slight variations in composition (such as the nature or content of plasticizers, binders, fillers, pigments, etc.) in many cases may affect radiation-stability properties quite drastically. Often a poorly rated product easily could be made to test higher by a slight change in raw materials or processing procedure.

The tests are empirical and have been developed only for immediate comparison purposes. Standard methods have not been established for radiation stability, chemical resistance or decontamination tests, and because of the variety and number of samples a few

Chemical Tests on Protective Coatings

Quantitative measurements were made to determine how radiation affects the chemical resistance and chemical decontaminability of protective coatings.

Resistance. *Standard chemical-resistance tests were run on irradiated and unirradiated specimens. Cold-rolled steel immersion rods ($^3/_8$ in. dia, 6-in. long) with one rounded end were coated with the paint to be tested and were irradiated to various levels of accumulated radiation. Specimens that did not "fail" (from visual observations) were immersed in several chemical reagents after an accumulated dose of about 10^9 r in air. The reagents were 3 molar nitric, sulfuric and hydrochloric acids, 3 molar sodium hydroxide, and an organic solvent (methyl isobutyl ketone or "hexone"). The tests were continued until failure, or for a total of 9 days, and the results with irradiated specimens were compared with those for unirradiated specimens.*

A second phase of the chemical resistance studies occurred in the process of preparing specimens for decontamination tests. Protective coatings were applied to aluminum, steel, and concrete panels and were irradiated to various levels of accumulated radiation. The test panels then were contaminated with 0.1 ml fission products in 6 M HNO_3. Many specimens that satisfactorily resisted 3 molar HNO_3 during immersion tests were attacked by the contaminating acid, so several decontamination studies were rerun with 3 molar contaminating acid.

Decontaminability. *The chemical decontamination procedure consisted of scrubbing specimens that withstood the contaminating acid with water, 3 M HNO_3, and in most cases concentrated citric acid. After each wash the surface of the specimens were monitored and a decontamination factor (DF) was calculated. The process of contamination and decontamination was repeated three times or until the coating failed.*

The tests were performed in series, and essentially only those coatings that "passed" the previous tests were subjected to later ones. Thus, only a few of the total number of coatings studied were carried through the decontamination tests.

In many cases, mounted coatings were irradiated on two or three different types of surfaces—aluminum, steel, and concrete. The series of tests was necessary since the stability of an irradiated coating was strongly influenced by the surface to which it was applied. Similar tests were performed for each type of coated panel.

Manufacturers of Organics Tested

UNMOUNTED COATINGS

A-89-A-Black—*Gordon-Lacey Chemical Products Co., N. Y., N. Y.*

Amercoat Strip, Amerplate (T-Locked, Black and White)—*Amercoat Corp., South Gate, Cal.*

Brevon-Black—*Atlas Powder Co., N. Chicago, Ill.*

GE Cocoon—*R. M. Hollingshead Corp., Camden, N. J.*

Tygofilm-Blue—*U. S. Stoneware, Akron, O.*

Flame-sprayed polyethylene—*Powder Weld Process Co., Brooklyn, N. Y.*

MOUNTED COATINGS

Alkaloy-550, Amphesive-801, Ampreg-E, Neobon, Zerox-110—*Atlas Mineral Products Co., Houston, Texas.*

Amercoat-23, 33, 44, 55 and 1574 SE—*Amercoat Corp., South Gate, Cal.*

Barrett silicone—*Barrett Varnish Co., Cicero, Ill.*

Corrosite-22—*Corrosite Corp., N. Y., N. Y.*

Duralon-36—*U. S. Stoneware, Akron, O.*

DuPont White—*DuPont Co., Inc., Wilmington, Del.*

Dyna-clad—*Merchants Chemical Co., Inc., N. Y., N. Y.*

Epon-395—*Glidden Co., Chicago, Ill.*

Epon-1001—*Shell Chemical Corp., N. Y., N. Y.*

Nukemite-40—*Nukem Products Corp., Buffalo, N. Y.*

Phenoline-3, Polyclad Sealcoat—*Carboline Co., St. Louis, Mo.*

Prufcoat—*Prufcoat Laboratory, Inc., Cambridge, Mass.*

Solar Silicone Alkyd—*Solar Corp., Milwaukee, Wis.*

Ucilon—*United Chromium, Inc., N. Y., N. Y.*

GASKETS AND ELASTOMERS

Polyethylene, plain and carbon-filled—*American Agile Co., Cleveland, O.*

Polystyrene—*Dow Chemical Co., Midland, Mich.*

Teflon—*Du Pont Co., Inc., Wilmington, Del.*

Kel-F—*Kellex Corp., N. Y., N. Y.*

Silicone rubber 12602 and 12603—*General Electric Co., Waterford, N. Y.*

Hycar rubber PA-21 and OR-25—*B. F. Goodrich Chemical Co., Cleveland, O.*

products may have received incorrect ratings.

Protective Coatings

The most important uses of protective coatings in radiochemical processing are to: (a) prevent corrosion of auxiliary process equipment (equipment not normally in contact with main process streams), and (b) improve the decontaminability of auxiliary equipment, the outside surface of main process equipment, and other surfaces such as the walls and floors of high-activity cells.

Coatings applied in various ways were irradiated with the Co^{60} gamma source. For convenience, several types of coatings that in actual use would be subjected to radiation while mounted on a surface were irradiated in an unmounted sheet form. These include stripcoats, a flame-sprayed polyethylene coating, and examples of "T-locked" plastic sheet. All other coatings were applied to either panels (aluminum, steel or concrete) or steel immersion rods.

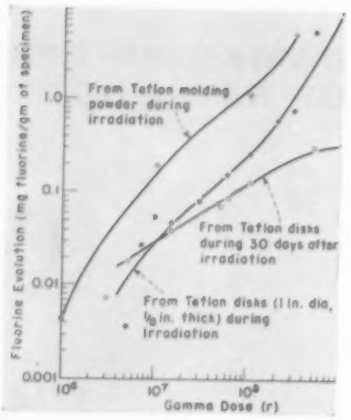


FIG. 1. Fluorine evolution from Teflon during and after irradiation

The acceptability or failure of an irradiated coating depends on the requirements of its use. In the same way, the types of tests used to study the effect of gamma radiation vary with the projected use of the coating.

Unmounted coatings. For the three types of coatings irradiated in sheet form, the strength of a coating-to-sur-

TABLE 1—How a Gamma Dose of 1.05×10^9 r* Damages Unmounted Coatings

Coating	*Polymer base*	*Color change*	*Flexibility*	*180-deg-bend test*	*Remarks*
Strip coats					
A-89-A	Vinyl	Black—unchanged	Stiff	Breaks	Sample curled
Amercoat Strip	Vinyl	White to gray	Stiff	Breaks	Sample curled
Brevon	Vinyl	Black—unchanged	Stiff	Breaks	Sample curled
GE Cocoon	Vinyl copolymer	Orange to black	Flexible	Bends	Tacky surface
Tygofilm	Vinyl copolymer	Blue to gray	Stiff	Breaks	Not curled
Plastic sheets					
Amer Plate (T-locked, black)	Vinyl	Black—unchanged	Stiff	Breaks	Not curled
Amer Plate (T-locked, white)	Polyethylene	White to amber	Stiff	Breaks	Not curled
Polyethylene (flame-sprayed)	Polyethylene	Red, yellow, and blue to darker shades	Stiff	Breaks	Not curled

* As measured in air.

TABLE 2—How Gamma Radiation Affects Protective Coatings

Coating	*Polymer base*	*Surface*	*Total gamma dose (10^8r)*	*Visual observations*
Alkaloy-550	Furane	Concrete panel	11.3*	No visible change
		Steel immersion rod	10*	No blistering or checking
Amercoat-23	Vinyl chloride	Concrete panel	12.3	Blistered, some cracks
		Steel panel	5	Blistered
		Steel panel—wet	10	One large blister on panel surface
Amercoat-33	Vinyl chloride	Aluminum panel	2.4	Blistered
		Concrete panel	12.2	Blistered, some cracks
		Steel panel—wet	10	Many pinpoint blisters
Amercoat-44	Vinyl	Steel panel—wet	10	Many pinpoint blisters
Amercoat-55	Vinyl	Aluminum panel	2.4	Blistered
		Concrete panel	12.3	Small blisters
		Steel panel	5	Blistered
		Steel panel—wet	10	Blistered
Amercoat-1574-SE	Epoxy	Concrete panel	12*	Tacky, some brittleness, discoloration
		Steel panel—wet	10*	Color streaked, some hardening
Amphesive-801	Modified phenolic	Concrete panel	11.3*	No visible change
		Steel immersion rod	10*	Drastically embrittled
Ampreg-E	Polyester resin	Concrete panel	10*	Layer of crystals on surface of coating
		Steel immersion rod—wet	2.3	
Barrett Silicone	Silicone-alkyd	Concrete panel	8*	
		Steel immersion rod	8*	
		Steel panel	8*	Blistered
Corrosite-22	Vinyl	Aluminum panel	2.4	Blistered, cracked
		Concrete panel	12.3	Dark orange spots (borderline case)
Duralon-36	Furane	Concrete panel	10*	Brittle
		Steel immersion rod	10*	Entire surface badly blistered
Dupont White	Vinyl chloride	Steel panel—wet	10	Entire surface badly blistered
Dyna-clad	Vinyl chloride	Steel panel—wet	10	
Epon-395	Epoxy	Steel immersion rod	8*	
		Steel panel	8*	Color, change from gray to green, hardened
		Steel panel—wet	10*	Tacky, some brittleness, splotchy discoloration
Epon-1001	Epoxy	Concrete panel	12*	
		Steel immersion rod	8*	
		Steel panel	8*	Hardened but no cracks or blisters
Neobon	Neoprene	Concrete panel	10*	Hardened on tip of rod
		Steel immersion rod	10*	
		Steel immersion rod—wet	2.3	Some crystallization below surface, much harder surface
		Steel panel	10*	
Nukemite-40	Vinyl	Aluminum panel	3.5	Blistered
		Concrete panel	12.3*	Surface soft, roughened
		Steel immersion rod	10*	
		Steel panel—wet	10	Few small blisters, color much darkened
Phenoline-3	Phenolic	Concrete panel	10	Visible cracks
		Steel immersion rod	10	Visible cracks
Polyclad Sealcoat	Vinyl chloride	Steel panel—wet	10	Surface badly wrinkled
Prufcoat	Styrene	Concrete panel	10	Hard, brittle craters, no blisters, darkened layer under surface
		Steel immersion rod	10	Checked, cracked, blistered
		Steel panel wet	1	Paint cracked from panel
Solar silicone alkyd	Silicone-alkyd	Concrete panel	8*	
		Steel immersion rod	8*	
		Steel panel	8*	
Ucilon	Vinyl chloride	Steel panel—wet	10	Surface blistered,
Zerox-110	Styrene butadiene	Concrete panel	11.3*	Extreme checking, darkened
		Steel immersion rod—wet	2.3	

* Discontinued before failure; all others were discontinued because of failure.

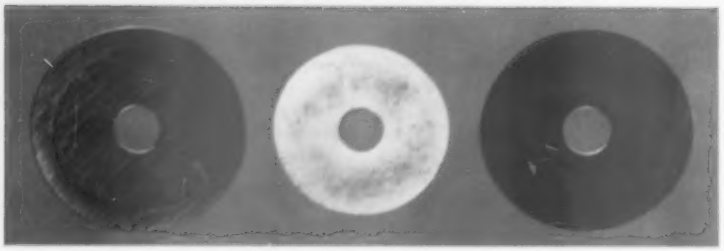


FIG. 2. Disassembled 347 stainless steel test flanges show corrosion resulting from contact with Teflon disk (center) during 10^8 r irradiation immersed in 50% HNO_3 for five days at 20° C

face bond normally is quite weak (for stripcoats, deliberately so), and radiation-caused changes in the bond are less important than changes in the physical properties of the coating. Gamma damage to unmounted coatings is shown in Table 1.

The main requirements for a radiation-resistant stripcoat are that the coating surface retain its integrity and the film its flexibility so that decontamination can be carried out by removing the coating after irradiation. In four of the five stripcoat tests, the surface remained intact, but the film became brittle and broke during a bending test; these stripcoats could not be removed readily after 10^8 r.

The fifth strip coat, G. E. Cocoon, remained flexible but the surface became very tacky. There is a possibility that the film porosity increased with irradiation, but no quantitative tests were carried out to establish this point.

The proposed use of both T-locked coatings and flame-sprayed polyethylene called for flexibility of the coatings. The unmounted tests indicated that both types were seriously embrittled by exposure to 10^9 r. However, applications without the need for flexibility (e.g., a T-locked surface for a concrete cell wall) would be possible provided that the sheet porosity had not increased. Again, porosity tests were not carried out.

Mounted coatings. Table 2 presents the results of screening studies of mounted protective coatings. It shows the gamma dose at which the coating failed or the maximum dose applied to the coating without failure.

The influence of the surface to which the coating is applied on the stability of the coating is seen by comparing the performance of a single coating type on several surfaces. The differences are often striking. For example, the vinyl coating Amercoat-33, which failed on an aluminum panel after 2.4×10^8 r, did not fail on a concrete panel until 1.22×10^9 r—over five times the gamma dose.

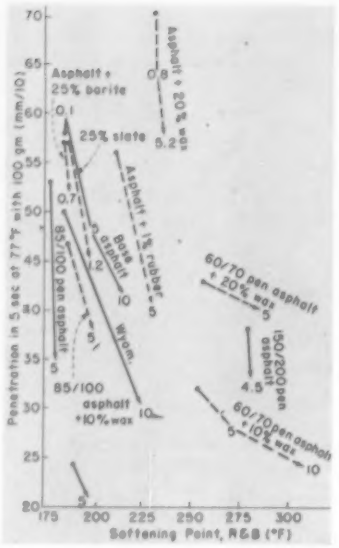

Penetration in 5 sec at 77°F with 100 gm (mm/10)
Softening Point, R&B (°F)
Asphalt + 25% barite
25% slate
Asphalt + 20% wax
Asphalt + 15% rubber
Base asphalt
85/100 pen asphalt
Wyoming
85/100 asphalt +10% wax
150/200 pen asphalt
60/70 pen asphalt + 20% wax
60/70 pen asphalt +10% wax

FIG. 3. Asphalts are hardened by exposure to gamma radiation—softening point and penetration change. Note that origin of each line is property of unirradiated sample; broken line denotes blend. Numbers show total dose, in 10^8 r

TABLE 3—How Gamma Radiation Affects the Chemical Resistance and Decontaminability of Mounted Coatings

Coating	*Surface*	*Gamma dose (10^8r)*	*Reagents*	*Results**				
				Acid	*Base*	*Solvent*	*C/D†*	*DF‡*
Alkaloy-550	Concrete	11.3	HNO_3-FP				R	25–200
	Steel	10	HNO_3, NaOH, hexone	R	R	R		
Amercoat-33	Aluminum	1.0	HNO_3-FP				R	70–117
Amphesive-801	Steel	10	HNO_3, NaOH, hexone	N	N	N		
Barrett silicone	Concrete	8	HNO_3-FP				R	12
	Steel	8	HNO_3, HCl, NaOH, hexone, HNO_3-FP	N	N	N	N	
Corrosite-22	Aluminum	1.0	HNO_3-FP				R	560
Duralon-36	Concrete	10	HNO_3-FP				R	40–200
	Steel	10	HNO_3, NaOH, hexone, HNO_3-FP	R	R	N		
Epon-395	Steel	8	HNO_3, NaOH, HCl, H_2SO_4, hexone	R	R	R	R	200
Epon-1001	Concrete	12	HNO_3-FP				R	5
	Steel	8	HNO_3, NaOH, HCl, hexone, HNO_3-FP	R	R	N	N	
Neobon	Steel	10	HNO_3, NaOH, hexone, HNO_3-FP	R	R	N	R	3–8
Nukemite-40	Steel	10	HNO_3, NaOH, hexone	N	N	N		
Solar silicone alkyd	Concrete	8	HNO_3-FP				R	8–15
	Steel	8	HNO_3-FP				N	

* Symbols for results: R = resistant; N = nonresistant.
† *C/D* is the process of HNO_3-fission product contamination and decontamination.
‡ DF is decontamination factor.

TABLE 4—How Gamma Radiation Affects the Physical Properties of Organic Gasket Materials

Gamma dose ($10^8 r$)	*Specific gravity* (gm/cm^3)	*Tensile strength* (10^3 *psi*)	*Shear strength* (10^3 *psi*)	*Elongation* (%)	*Breaking energy* (*ft-lb per in. of notch*)	H_2O *absorbed* (%)	*Haze* (%)	*Hardness* (*Rockwell R*)
Polyethylene								
0	0.914	1.56	1.89	325	11.2	0.026	1.72	−8.5
1	0.920	1.64	1.81	28	5.6	0.035	1.83	14.3
10	0.921	1.90	1.91	7.6	2.9	0.027	98	49.2
Polyethylene, 1% carbon filled								
0		1.59	1.76	450	10.3			−6
5		1.65	2.09	10–30	3.1			34
10		1.80	2.15	10–30	2.9			66
Polystyrene								
0	1.049	4.64	5.9	0.75	0.45	0.054	12.5	124
0.01		4.2	5.5	0.78	0.29			124
0.1		5.4	6.1	1.03	0.23			124
1	1.051	3.3	5.6	0.45	0.30	0.089	8.3	122
10	1.053	5.0	5.6	0.99	0.19	0.089	14.2	121
Teflon								
0	2.14	3.76	3.01	175	2.65	0.0053	5.5	
1	2.21	Failed	0.483	Failed	0.37	0.014	14.6	
10	2.19	Failed	0.094	Failed	0.30	0.345		
Kel-F								
0		2.55	3.41	264				
0.01		2.40	3.65	230				
0.1		1.67	1.85	73				
1		Failed	Failed	Failed				

In most cases the greater stability of coatings on concrete may be attributed to: (a) the greater chemical resistance of concrete to attack by gaseous and liquid decomposition products from the coating, and (b) the absorption of these products in the porous concrete structure. In the case of vinyl coatings, the chemical attack that takes place is from halide acids.

Of the 23 mounted coatings tested, only four polymer-base types did not fail at the maximum doses used: furanes, epoxys, silicone-alkyds, and one modified phenolic specimen. Eight coatings that exhibit radiation stability, plus three examples of low-irradiated vinyl coatings and one neoprene-base coating, were tested for chemical stability and decontaminability after irradiation.

Table 3 shows that six of the irradiated coatings are not resistant to the organic solvent hexone. In addition, several lacking solvent resistance also do not resist either acids or a base. Two other coatings, the vinyl-based Amercoat-33 and Corrosite-22, show good decontaminability but fail at higher gamma doses (2.4×10^8 r). The silicone-alkyd coating is difficult to decontaminate on concrete and fails on a steel-panel surface during the process of its contamination.

Two types of coatings, one each of the furane-based and epoxy-based coating (Alkaloy-550 and Epon-395), show excellent chemical resistance and decontaminability. The other two coatings of similar polymer base, Duralon-36 and Epon-1001, both lack solvent resistance after irradiation.

Gasket Materials

Gasket materials were irradiated in leakproof containers lowered into a vessel surrounded by Co^{60} slugs. Radiation intensity varied, but only the total dose of each specimen is recorded in Table 4.

In early tests, corrosive gases containing fluorine were detected being evolved from irradiated Teflon. Tests were made to determine the quantity of fluorine evolved from Teflon disks (1 in. dia., ¼ in. thick) and Teflon molding powder during irradiation, the quantity of degraded fluorine within the irradiated disks that was released during the 30-day period immediately after irradiation, and the effects of these gases on stainless steel flanges carrying 50% HNO_3 solutions. To measure the quantity of fluorine evolved, the specimens were immersed in a NaOH solution during irradiation, and then the solution was analyzed for fluoride content. No attempt was made to determine in what compounds the fluorine was evolved.

In many cases only one reading could be obtained from each specimen; so several specimens were necessary for each series of tests. Since perfectly uniform specimens could not be obtained, only changes in properties that are greater than the variations in the specimens could be detected.

Results. The most evident observation is the difference between the radiation stability of halogenated polymers, Teflon and Kel-F, and nonhalogenated polymers, polyethylene and polystyrene (see Table 4). Both Teflon and Kel-F evolve corrosive gases and are degraded completely by irradiation to 10^8 r, while polyethylene and polystyrene appear very resistant to irradiation to and beyond this level.

Polyethylene, polystyrene. The only major difference between the behavior of polyethylene and polystyrene is the marked increase in the hardness of polyethylene after irradiation. Polystyrene is the most resistant gasket material tested and probably would be satisfactory for use at radiation levels up to 10^9 r. But the rate of hardening of polyethylene may limit its use to ra-

diation dosages of about 10^9 roentgen.

Since inorganic fillers often make organic plastics more resistant to radiation, a 1%-carbon-filled polyethylene was tested to compare this material with natural polyethylene. But no difference in stability could be detected.

Corrosive gases. Corrosive gases evolving from gaskets during irradiation not only indicate deterioration of the gasket, but the gases also may damage flanges or other equipment. No evolution from Teflon is detected at radiation levels less than 10^6 r (see Fig. 1). The appreciable quantity of fluorine given off by the Teflon disks during the 30-day period after irradiation and the difference between the quantity of fluorine evolved from the disks and the molding powder show that released fluorine is accumulated within the specimen before diffusing through the surface. Data on halide evolution from polymonochlorotrifluoroethylene and more complete data on changes in the physical properties of Kel-F are reported elsewhere (*1*).

Flange corrosion. Figure 2 shows how these gases affect stainless steel flanges immersed in 50% HNO_3. A light brown area is noted on the flange where the steel had been in contact with Teflon. Microscopic examination reveals masses of tiny pits; all other surfaces of the flange remain as bright as before the test. Control specimens of stainless steel in the gamma field (without contact with Teflon) were corroded by 50% HNO_3 at a rate less than 1 mil/yr. No difference could be detected between the corrosion rates of the control specimens with and without irradiation.

Hycar, silicone rubber. As shown in Table 5, the elastomeric properties of Hycar and silicone rubber are stable at radiation levels not greater than 10^7 r. However, between 10^7 r and 10^8 r there are considerable changes in the properties of both materials, largely embrittlement processes. After 10^8 r both types of silicone rubber deteriorate to a material with approximately the same mechanical properties.

TABLE 5—How Gamma Radiation Affects Gasket Materials

Gamma dose (*r*)	*Tensile strength* (10^3 *psi*)		*Tensile strength* (% *change*)		*Elongation* (%)		*Elongation* (% *change*)		*Hardness* (*Shore*)	*Hardness* (% *change*)
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*A*
Silicone 12602										
0	0.277				58				62	
10^4	0.245		−12		50		−14		65	4.8
10^5	0.260		−6.1		62		6.9		66	6.5
10^7	0.282		1.8		25		−57		74	19
10^8	0.151		−46		5		−91		95	53
Silicone 12603										
0	0.555				36				84	
10^4	0.540		−2.7		36		0		84	0
10^6	—		—		—		—		85	1.2
10^7	0.528		−4.9		25		−31		87	3.6
10^8	0.135		−76		5		−86		86	2.4
Hycar OR-25*										
0	2.74	2.26			275	365			72	
10^4	1.88	2.33	−32	3.1	230	371	−16	1.6	77	6.9
10^5	2.42	2.40	−12	6.2	255	358	−7	−1.9	78	8.3
10^7	2.59	2.64	−5	17	208	185	−24	−49	81	13
10^8	1.63	2.04	−40	−9.7	35	32	−87	−91	92	28
Hycar PA-21*										
0	1.36	1.57			190	145			71	
10^4	1.29	1.40	−5.1	−11	155	130	−18	−10	70	−1.4
10^5	1.33	1.40	−2.2	−11	150	130	−21	−10	73	−2.9
10^7	1.33	1.38	−2.2	−12	135	106	−29	−27	72	1.4
10^8	0.81	0.97	−40	−38	50	41	−74	−72	80	13

* Two series of tests (A and B) were made with these materials.

Asphalts and Tars

The need for a cheap method of indefinitely storing radioactive waste solutions resulting from the reprocessing of spent reactor fuels prompted an investigation of impervious lining materials for earthen basins. Asphalts and tars, because of cheapness and ease of application, were selected for tests of radiation damage and chemical resistivity.

As shown in Fig. 3 and Table 6, asphalts and tars retain their ductility and are hardened (but not excessively) with increasing exposure up to 10^9 r total dose. From the slopes of the lines, there is evidence that excessive hardness may occur at 10^{10} r.

Asphalts and tars evolve gases (principally hydrogen) during irradiation. The asphalt assumes a vesicular or honeycombed structure of individual cells that probably would not develop leaks in actual service. Irradiated tars exhibit this structure to a slight extent. Both are adequately resistant to neutralized radioactive wastes up to 200° F, but attack by acid wastes is severe.

Thus, asphalts and tars (if a suitable cheap radiation-resistant reinforcing material for the tar can be found) can be used to contain radiochemical wastes in earthen basins if: (a) the total dose does not greatly exceed 10^9 r, (b) the wastes are neutralized, and (c) the temperature of the stored waste is not permitted to rise above 200° F.

It is estimated that an earthen basin of 10^6 gal capacity can be constructed with a ½-in.-thick asphalt lining, covered with 2 ft of compacted earth and complete with roof, for 3–5¢/gal of stored waste.

Ion Exchange Resins

Preliminary work has established the order of magnitude of radiation damage to ion exchange resins as shown by a loss in capacity. While the capacity loss is possibly the most important factor in the use of ion exchange resins for radiochemical processing at high activity levels, other effects that must be considered include changes in the physical and chemical character of the material. Figures 4 and 5 show the effect of Co^{60} gamma rays on the capacity of Dowex A-1 anion exchange resin and on Dowex 50 cation exchange resin as a function of the energy absorbed. A third resin, Dowex 30, a sulfonated phenolic cation exchange resin, shows a capacity loss of only 1% per watt-hr of energy absorbed per gram as compared

TABLE 6—How Gamma Radiation Affects Coal Tar Products*

Characteristic	*Roofing pitch*		*W. G. millwrap enamel*		*Pipeline enamel*		*Waterworks enamel*	
Gamma dose, r	0	5×10^8	0	5×10^8	0	5×10^8	0	5×10^8
Softening point (ASTM D36), °F	—	—	199	203	192	197	237	248
Softening point (ASTM D61), °F	158	161	—	—	169	168	—	—
Penetration at 77° F, 100 gm, 5 sec, mm/10	5.5	5	9	8.5	0	0	15	7.5
Penetration at 32° F, 200 gm, 60 sec, mm/10	0	0	1	1	0	0	5	0.5
Penetration at 115° F, 50 gm, 5 sec, mm/10	84	70	26	24	1.5	1.5	31	22.5
Ductility at 77° F, 5 cm/min, cm	67	17.5	2	2	0	0	3	1.5
Ductility at 90° F, 5 cm/min, cm	—	—	—	—	1.5	1	—	—
Ash, %	0.08	1.04†	30.7	28.2	16.9	16.8	29	29.5

* Test specimens supplied by the Barrett Div. of Allied Dye and Chemical Corp., Edgewater, N. J.
† Similar to ferric oxide residues, probably due to metallic contamination.

to the losses of 15–40% for Dowex A-1 and Dowex 50. The variations in capacity loss demonstrate that radiation damage can perhaps be minimized with the proper choice of resin, provided that the chemical stability of the resin is satisfactory (*2*).

Decomposition of Dowex 50W resin by alpha bombardment is observed when Am^{241} is isolated and concentrated by cation exchange. During loadings of about 0.5 gm Am per liter of resin, darkening, presumably charring, of the resin bed is observed within 24 hr (*3*). But this phenomenon does not deleteriously affect the cation-exchange procedure.

Aqueous Solutions

The chemical effects produced by ionizing radiations on aqueous solutions can be divided into two parts: (a) indirect action of H and OH radicals formed by water decomposition reacting with solute particles and with one another, and (b) direct action of radiation on solute particles followed by chemical change. The primary mechanism of water decomposition is

$$H_2O \rightarrow H + OH \qquad (1)$$
$$2H_2O \rightarrow H_2 + H_2O_2 \qquad (2)$$

The radicals H and OH are available for reaction with solutes or with one another to form H_2 and H_2O_2. In regions of low ionization density, most radicals react with solutes, while in regions of high ionization density, radicals recombine to form the products shown in Eq. 2. Since H, OH, H_2O_2, and the intermediate perhydroxy radical HO_2 are either strong oxidizing or reducing agents, oxidation or reduction reactions occur with many of the solutes present. In the direct absorption of radiation by the solute, oxidation or reduction results, since electrons are transferred or removed in the process.

Chromium^{VI} ions, for example, are reduced to trivalent chromium in acidic acetic acid-sodium acetate buffered solutions when subjected to intense gamma radiations. The reduction rate of a 0.5 *M* chromate solution buffered with 4.0 *M* acetate is 2.35 ± 0.15 millimoles/kcal at *p*H 4 in a gamma field of about 10^7 r/hr. The decomposition rate is reduced to 0.51 ± 0.15 millimoles/kcal by the addition of 0.5 *M* sodium bromide as a "protector" (*4*).

* * *

The authors wish to acknowledge the assistance of the following in carrying out the radiation-damage test program for protective coatings and gaskets: A. J. Hoiberg, Lion Oil Co., a division of Monsanto Chemical Co.; G. A. West, F. L. Rogers, G. R. Guinn, R. J. McNamee, Union Carbide Nuclear Co. (ORNL); M. Tyner, Jr., Univ. of Florida; J. N. Hunsberger of E. I. du Pont de Nemours & Co.; and the various companies that supplied specimens.

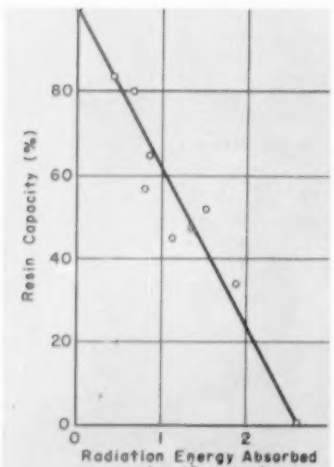


FIG. 4. Capacity loss of Dowex A-1 anion-exchange resin (quaternary amine polystyrene) caused by Co^{60} gammas

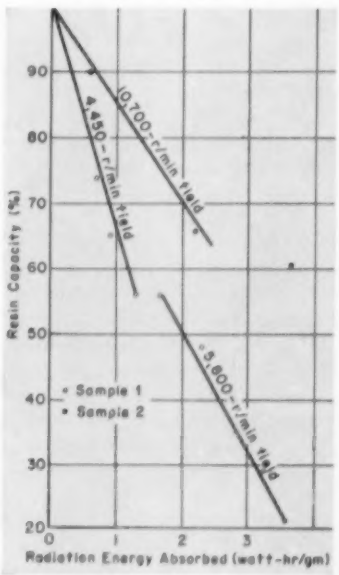


FIG. 5 (right). Effect on Dowex 50 cation-exchange resin (sulfonated polystyrene)

BIBLIOGRAPHY

1. *Ind. Eng. Chem.* **48,** 2549 (1953)
2. G. I. Cathers, "Radiation Damage to Radiochemical Processing Reagents," Paper 584, Geneva Conference on Peaceful Uses of Atomic Energy (1955)
3. R. H. Rainey, ORNL, personal communication (1956)
4. R. L. Andelin, E. L. Anderson, IDO-14347 (1955)

BENEFICIAL EFFECTS OF RADIATION

On Polymers

By ARTHUR CHARLESBY
Tube Investments Research Laboratories
Hinxton Hall
Cambridge, England

MODIFICATIONS OF POLYMERS by radiation appear to have commercial possibilities, but insufficient data and the cost of radiation block, at least for the present, most large-scale applications.

Effects that have been observed include changed mechanical and electrical properties and controlled molecular weights. More specialized applications of promise are rubber vulcanization without the use of chemical agents and foamed insulating materials.

In discussing the effect of high-energy radiation on polymers, no basic distinction is made between elastomers (e.g., butadiene-styrene copolymer) and plastomers (e.g., polystyrene), between crystalline (Teflon) and amorphous (polymethyl methacrylate) structures, between naturally occurring polymers (e.g., cellulose and rubber) and synthetic materials (e.g., nylon or polyethylene). The only restriction is on the shape of the molecule, which must be linear or branched—only in this case are considerable physical changes likely to occur at moderate doses. These results may indeed be extended to materials such as vulcanized rubber in which the number of bridges between molecules is sufficiently low to make the additional contribution of radiation-induced bridges of significant value. But their application to the conventional thermoset plastics, such as phenol formaldehyde, is of no commercial interest.

Nature of the Effects

The marked changes in properties of many long-chain polymers after irradiation arise primarily from the rearrangement of their bond structure.

Prior to irradiation the polymers are bound to each other by weak Van der Waals forces. They owe their solid behavior either to the stiffness of the chains, which retains the entanglements and prevents the chains from slipping past one another, or to the regularity of the side chains, which permits the polymer molecules to crystallise. In the latter case the weak forces between molecules reinforce one another. In either case the system is very temperature sensitive, and the materials melt and flow as the temperature rises—in the former case by reducing the stiffness of the molecules, allowing them to slip past one another when an external force is applied; in the latter case by melting the crystalline regions.

The effect of radiation exposure follows one of two paths. It may fracture side chains and form radicals, which eventually combine to link adjacent molecules together; or it may fracture the main chain and reduce the average molecular weight. The former process—crosslinking—is of great potential industrial importance. The latter—degradation—is of considerable scientific interest, but of much less commercial significance.

The cause of this fundamental difference in behavior of polymers under radiation has attracted considerable interest. This pattern of behavior has been related by some to the thermal polymerization of the appropriate monomer units. Others have pointed out that in vinyl polymers degradation occurs primarily for polymers containing a tertiary carbon $(—CH_2—CH_1R_2—)_n$, whereas crosslinking ensues for vinyls of the formula $(—CH_2—CHR—)_n$. Steric hindrances between sidechains may well account for these differences. Polyisobutylene $(—CH_2—C(CH_3)_2—)_n$ possesses considerable steric hindrance as shown in X-ray studies; the polymer degrades under radiation. In the comparable dimethyl siloxane $(—O—Si(CH_3)_2—)_n$ the chain is much straighter, and the steric hindrances are reduced. This polymer crosslinks.

Although it is usual to divide polymers into two distinct groups—those that crosslink and those that degrade—it is not certain that this distinction is a completely valid one. Polyethylene, for example, both crosslinks and degrades, the former reaction predominating. Other polymers such as polyacrylic acid in aqueous solution degrade at low concentration and crosslink at high concentrations in the solid. Both reactions have been found to occur with a series of acrylic esters.

Chain Fracture

For polymers that suffer main-chain fracture on irradiation, the resultant decrease in average molecular weight differs from that arising from thermal depolymerization. In the latter case a chain reaction is involved, and once a main chain bond is broken a considerable degree of depolymerization takes place, with consequent production of monomer. On the other hand, in radiation-induced degradation only one or two monomer units are affected by each break; after a small amount of atomic arrangement in the neighborhood, two stable polymer molecules are formed.

The location of fracture is random along the chain and the molecular weight distribution rapidly approximates a random or exponential distribution

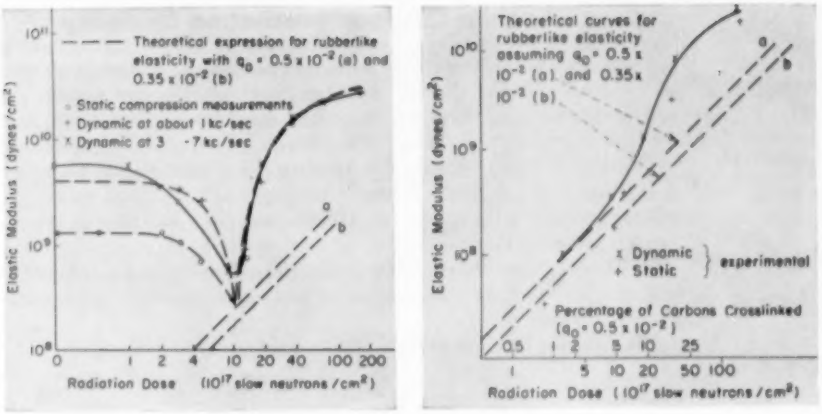

Theoretical expression for rubberlike elasticity with $q_0 = 0.5 \times 10^{-2}$ (a) and 0.35×10^{-2} (b)
Static compression measurements
Dynamic at about 1 kc/sec
Dynamic at 3 - 7 kc/sec
Elastic Modulus (dynes/cm²)
Radiation Dose (10^{17} slow neutrons/cm²)
Theoretical curves for rubberlike elasticity assuming $q_0 = 0.5 \times 10^{-2}$ (a) and 0.35×10^{-2} (b)
x Dynamic
+ Static
experimental
Percentage of Carbons Crosslinked ($q_0 = 0.5 \times 10^{-2}$)

FIG. 1. Effect of radiation on elastic modulus of polyethylene. At left is the effect at 20° C and at right at 150° C, above the melting point

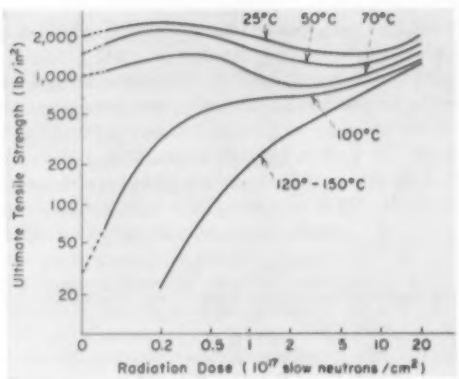


FIG. 2. Ultimate tensile strength of irradiated polyethylene

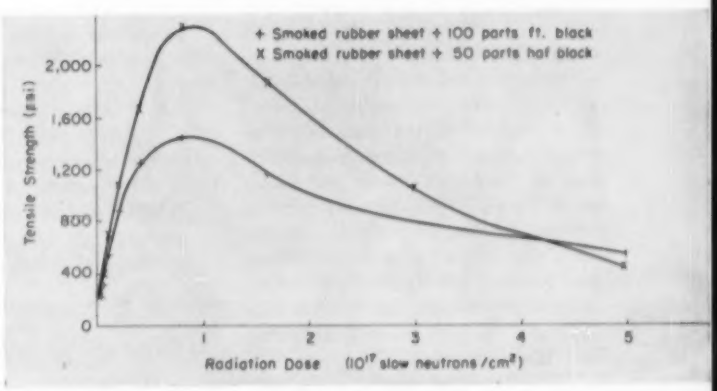

+ Smoked rubber sheet + 100 parts ft. black
X Smoked rubber sheet + 50 parts haf black
Tensile Strength (psi)
Radiation Dose (10^{17} slow neutrons/cm²)

FIG. 3. Tensile strength of irradiated rubber-carbon black

$$n(M) \propto e^{-M/M_n}$$

where $n(M)$ is the number of molecules of molecular weight, and the average is M_n. This average value M_n is related to the radiation dose

$$1/M_n = 10^{-6}GD + 1/M_{no}$$

where M_{no} is the initial (number average) molecular weight and its reciprocal often is very small compared with $1/M_n$. Thus, radiation offers a simple and reproducible means of reducing the average molecular weight of a polymer to any required extent, with a known molecular weight distribution. This has been carried out for native dextran subjected to 800-kv electrons, where both chain fracture and branching is observed to occur proportionately to the radiation dose. By this means a clinically useful material can be produced. The method also can be used to obtain useful numerical constants to characterize polymers by means of their intrinsic viscosity.

Mechanical Effects

Among the polymers that crosslink as a result of irradiation, polyethylene has received by far the most detailed attention. As usually prepared under conditions of high temperature and pressure, the polymer is highly branched. Thus, the crystals present in the polymer are very limited in size, and melt at temperatures of up to about 115° C. Polyethylenes prepared at lower temperature and pressure conditions have reduced branching; their crystalline regions are more extensive and melt at higher temperatures of up to 135° C. In either case the molten polymer flows as a viscous fluid.

After irradiation has produced crosslinking between molecules, this behavior is basically altered. For low doses of 50–100 megarads the density of crosslinking is still relatively low (about 1% of the monomer units crosslinked); the physical properties are not greatly affected at room temperature or below, since the crystalline regions are still present to bind the molecules together.

As the temperature is raised the crystals still melt, at a slightly reduced temperature, but the polymer molecules are now held together by radiation-induced crosslinks and can no longer flow. Instead of being converted to a viscous fluid, the irradiated polymer now has rubber-like elastic properties. At these higher temperatures both the tensile strength and elastic modulus increase with density of crosslinking, i.e., radiation dose.

Elastic properties. The elastic modulus E in particular follows the theoretical formula for rubberlike elasticity (Fig. 1)

$$E = 3\rho RT/M_c$$

where ρ is the polymer density, R is the gas constant, T the absolute temperature, and M_c is the average molecular weight between crosslinks. The G value for crosslinking of polyethylene is not known accurately, but is close

to 3. Since D megarads produce

$$(6.25 \times 10^{17}/6.02 \times 10^{23})GM_cD$$

chemical changes per molecular weight M_c, and this product must equal 0.5 (since there are two crosslinked units per crosslink, and the number of chains of length M_c equals the number of crosslinked units)

$$1/M_c = 12.5 \times 10^{17}GD/6.02 \times 10^{23}$$
$$E = 3RT \times 12.25 \times 10^{17}GD/6.02 \times 10^{23}$$
$$\simeq 6 \times 10^5 D$$

This expression enables calculation of the radiation dose to produce a polyethylene with any required elastic modulus above its melting point to be calculated and hence costed, if the cost of radiation is known.

For higher radiation doses, unlikely to be of widespread industrial importance because of the high radiation costs involved at present, radiation reduces and eventually eliminates crystallinity, even at room temperatures. Although irradiated polyethylene then behaves as a flexible rubber-like material, the high radiation doses and correspondingly high crosslinking densities represent over-vulcanization, and the material produced is somewhat brittle and cheesy. At very high radiation doses (1,000 megarads or greater), irradiated polyethylene acquires many of the mechanical properties of glass.

No theoretical expressions for the tensile strength or elongation at break as a function of radiation dose are available. Some experimental results are shown in Fig. 2.

Improved high-temperature behavior. The improvement in mechanical properties of irradiated polyethylene enables it to be used at higher temperatures. The improved temperature behavior acquired due to radiation is not directly comparable with the new high-temperature forms of unirradiated polyethylene. The latter are stiffer at room temperature, and can be used at temperatures some 20° C beyond the older type of polyethylene. However, above this higher temperature they do melt and flow.

The melting point of polyethylene is not raised by radiation, but above this

How to Compute Cost and Irradiation Efficiency

The amount of chemical change induced by radiation is commonly expressed as G—the number of chemical bonds modified per 100 ev absorbed. The energy required to produce one ion-pair in air is 34 ev, i.e., G ≅ 3; many chemical reactions have G values of about 3.

Where G is known for a chemical process, the irradiation cost can be computed based on the following factors:

1. *Production cost of high-energy radiation—includes amortization of radiation equipment and operating costs.*
2. *Beam-utilization factor—losses depend on geometry and specimen type.*
3. *Required radiation dose—varies greatly with application, but can often be calculated from G values.*

The following expressions are useful in computing cost and output.

1 kwh = 3.6 × 10⁶ joules = 3.6 × 10¹³ ergs = 2.25 × 10²⁵ ev
1 megarad = 10⁶ ergs absorbed per gram of irradiated material

Thus 1 kwh of absorbed energy can give 1 megarad of radiation to 3.6 × 10⁵ gm of material. Thus, about 1 kwh fully absorbed can treat 800 lb to 1 megarad or X lb to 800/X megarads.

Since 1 megarad liberates 10⁶ ergs/gm or 0.625 × 10²⁰ ev/gm, it produces 6.25 × 10¹⁷ G chemical changes per gram. The number of molecules of molecular weight M per gram of material is 6.02 × 10²³/M. Thus the proportion of molecules changed is (6.25 × 10¹⁷/6.02 × 10²³)GMD = 10⁻⁶ GMD, where D is the radiation dose in megarads. This assumes a yield proportional to D and the appropriate value of G. If G = 3.3 and M = 300, the proportion changed is 10⁻³ D; a total dose of 1,000 megarads is needed for an average of one chemical change per molecule.

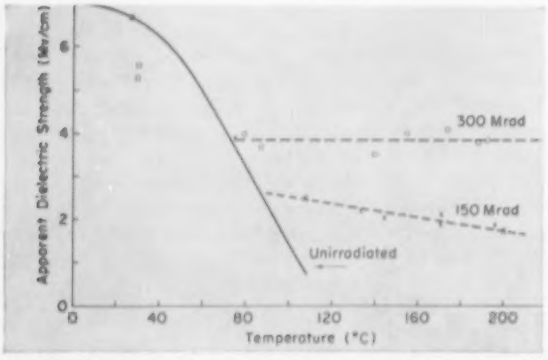


FIG. 4. Dielectric strength of polyethylene irradiated with 2-Mev electrons. Values calculated from initial sample thickness

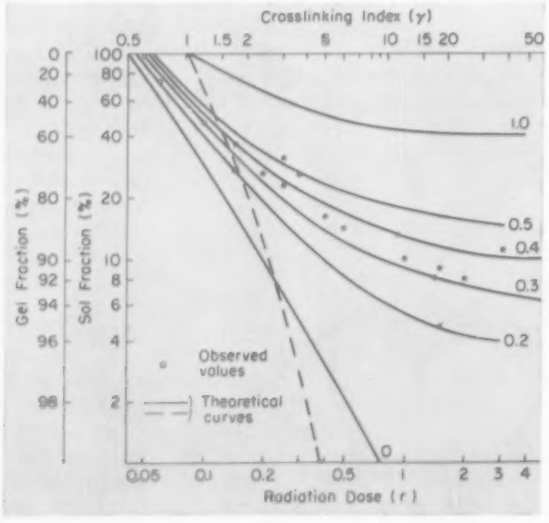


FIG. 5. Sol and gel fractions of irradiated polyethylene. In theoretical curves, solid lines assume initial random weight distribution (numbers are fracture-to-crosslinking ratios); broken line assumes uniform initial distribution (no chain fracture)

temperature it does not flow, and is instead changed to a rubberlike material.

This rubberlike property can be made use of in the so-called memory effect. Lightly irradiated polyethylene heated above its melting point can be molded to any desired shape, which it will retain on cooling. Thus vacuum molding of large objects from irradiated sheet becomes a relatively simple process. Shapes can always be reformed by reheating to recover the initial irradiated sheet.

Vulcanization of rubber. Rubber can be crosslinked by radiation. The product is similar to conventionally vulcanized rubber, but does not require the chemical vulcanizing agents.

The degree of cure for maximum tensile strength (Fig. 3) requires a radiation dose of about 40 megarads, so that 1 kwh of radiation energy produces only 20 lb of material. Thus cost is too high to be justified except for valuable new properties.

One advantage of this technique is that different degrees of vulcanization can be given readily to different parts of the same specimen. For silicone rubbers, in which the additional cost of radiation treatment can be covered more readily, the absence of vulcanizing agents may be a useful advantage.

If rubber is stretched and subsequently irradiated in this condition, a crosslinked product is obtained with elastic properties differing in two directions. This novel behavior may be of interest for special applications.

Other polymers. Other polymers that may be crosslinked by radiation include nylon, polyvinyl acetate, polyvinyl chloride, and the acrylic esters.

In crystalline or glass-like polymers there are few marked changes in mechanical properties at low temperatures. However, above the melting point or second-order-transition temperatures a rubberlike material is produced at radiation doses that depend on the G value for crosslinking—generally 5–100 megarads. Only for much higher doses are there marked changes in mechanical behavior in the crystalline or glass-like state, accompanied by a low elongation at break in the rubberlike state.

Electrical Properties

The electrical properties of irradiated polyethylene, at least for low radiation doses, are not greatly changed (Fig. 4).

The dielectric strength decreases with increasing temperature, as for unirradiated polyethylene, but unlike the latter, reaches a minimum value and subsequently increases slowly; this pattern of behavior is directly parallel to the elastic modulus, and indicates that the cause of electrical breakdown is mechanical failure in compression.

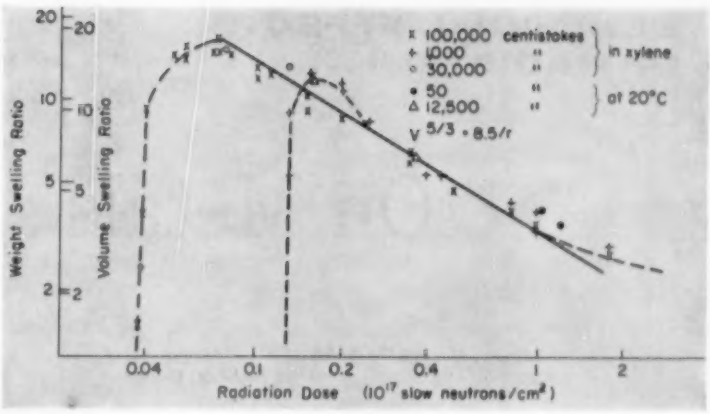


FIG. 6. Swelling of irradiated dimethyl siloxanes

Solubility—Gel Formation

Crosslinking changes the solubility of irradiated polymers. Up to a certain radiation level, polymers are still completely soluble, but beyond it the soluble fraction decreases rapidly with increasing radiation dose, although the gel will still swell in the usual solvent.

The critical radiation dose, at which some insoluble material first appears, is termed the gel point, and occurs when there is on the average one crosslinked unit per "weight average" molecule. The shape of the gel-radiation-dose curve depends on the initial molecular weight distribution of the polymer.

The radiation dose needed to reach the gel point can be calculated readily if the G value for crosslinking is known. For a weight average molecule of molecular weight M_w, D megarads will provide $6.25 \times 10^{17} G M_w D / 6.06 \times 10^{23}$ crosslinks. Since an average of 0.5 crosslinks or 1 crosslinked unit per molecule M_w is needed for incipient gel formation

$$D_{gel} = 0.5 \times 6.02 \times 10^{23}/6.25 \times 10^{17} G M_w$$

Thus if $G \simeq 3$ and $M_w = 10^5$; $D_{gel} = 1.6$ megarads. If radiation causes main chain fracture and degradation, as well as crosslinking, the gelling dose will be increased (Fig. 5).

For radiation doses beyond the gel point, a polymer that has been crosslinked by radiation consists of two phases—one soluble, the other insoluble, crosslinked, and forming a three dimensional network (gel). By increasing the radiation dose, the soluble fraction may be reduced to any required extent, but only tends to zero theoretically for infinite radiation dose.

For polymers that both crosslink and degrade, the limiting soluble fraction is finite and characteristic of the crosslinking/fracture ratio. The gel fraction of a crosslinked polymer, although insoluble, swells in solvents for the uncrosslinked material. The degree of swelling depends on the density of crosslinks (denoted by ρ, the polymer density or proportion of monomer units crosslinked) and a parameter μ determined by the interaction between polymer molecule and solvent. This relationship can be written in an approximate form if end corrections are ignored (i.e., if M_c is much smaller than the initial average molecular weight M_w)

$$V^{5/3} = (0.5 - \mu) M_c / \rho v$$

where V is the swelling ratio (swollen polymer/dry polymer), and v is the molar volume of the solvent. Thus

$$V^{5/3} = (0.5 - \mu)/\rho v\, 2.08 \times 10^{-8} G D$$

If $\mu = 0.44$, $\rho = 1$, $v = 100$ and $G = 3$, then $V^{5/3} = 100/D$, so that a radiation dose D of 10 megarads gives a fourfold swelling ratio. The formula assumes that V is much greater than one and cannot be extended to very low degrees of swelling.

Solubility and swelling can be likewise reduced by radiation (Fig. 6), but at the doses available for large-scale treatment still remain appreciable. Polystyrene follows this same pattern of behavior except that due to protection effects the radiation doses involved must be considerably increased.

BENEFICIAL EFFECTS OF RADIATION...

On Metals

By H. A. SALLER*
Battelle Memorial Institute, Columbus, Ohio

THE BENEFICIAL EFFECTS of radiation on metals may be considered under two conditions:

1. Continuous irradiation as a reactor material.
2. Deliberate exposure to radiation to improve selected properties.

Reactor Materials

Although deleterious effects on reactor materials have been a prime concern, little has been done to benefit from radiation effects. Greatest consideration must be given to fuel, fuel cladding, and structural materials.

Fuels. The changes in properties that occur in uranium during reactor exposure are probably caused by a combination of effects from radiation and thermal cycling.

These effects cause the following changes in uranium: density decreases slightly, hardness increases, thermal conductivity is decreased by about 10%, ductility is markedly decreased, ultimate strength is decreased, and the yield strength is increased (*1*). Weber (*2*) has suggested further that these changes are associated with the alpha phase of uranium, which is anisotropic in nature. If uranium could be maintained in the gamma phase, which is isotropic, many of the harmful effects of radiation probably could be reversed.

It is possible to retain a metastable gamma-phase uranium by alloying. The limitation of this technique, however, is that relatively large amounts of a second element are required to stabilize the gamma phase. Even if the required amount of an alloying element can be tolerated, there is danger of decomposing the gamma phase through prolonged heating or thermal cycling.

Experimental results have been reported on a uranium alloy that was apparently transformed to the more stable gamma phase by the effects of radiation (*3*). The alloy contained 9 wt% molybdenum. Such an alloy, when rapidly cooled from above 600° C, is a homogeneous solid solution of molybdenum in gamma uranium. Annealing such an alloy (100 hr at 500° C) causes it to transform to a heterogeneous mixture of alpha uranium and an intermetallic compound epsilon. As is shown in Table 1, the homogeneous gamma-uranium alloy is unaffected by radiation, while the heterogeneous alpha-uranium alloy is transformed to the homogeneous condition. This latter condition is more favorable for resistance to radiation damage.

Other phase reversion studies include a number of uranium-molybdenum alloys and several uranium-niobium alloys (*4*). Their results support the idea that relatively small amounts of radiation tend to produce the isotropic gamma phase in both uranium-molybdenum and uranium-niobium alloys.

In the case of these two alloy systems, there is definite evidence of beneficial effects of radiation. This behavior might well extend to other alloy systems.

TABLE 1—Properties of Uranium Alloys under Irradiation (*3*)

Heat treatment	*Density*	*Specific electrical resistivity* (*ohm-mm²/m*)	*Thermal coefficient of electrical resistivity* (10^{-3}/°C)	*Microstructure*
Quenching (homogeneous state)				
Before irradiation	17.26	0.686	0.01	Homogeneous
After irradiation	17.23	0.682	0.01	Homogeneous
Quenching, annealing at 500° C for 100 hr (heterogeneous state)				
Before irradiation	17.35	0.531	1.5	Heterogeneous
After irradiation	17.20	0.682	0.01	Homogeneous
Same as 2nd case				
Before irradiation		0.523	1.14	
After irradiation		0.603	0.39	

* Mr. Saller passed away on August 14th.

Cladding and structural materials. While the effects of radiation on the cladding and structural materials of a reactor are not complicated by anisotropy of the metals, as is the case for uranium, the results are comparable. There is a general tendency for increased hardness and yield strength while ductility is reduced. Results on typical alloys are shown in Table 2.

In reactor designs considered so far, these changes in properties of structural materials have not been utilized to any great extent. For many applications, such as cladding, the reduced ductility after irradiation has, in fact, been harmful. It is reasonable to believe, however, that by proper design, a harder, stronger material can be an asset in spite of its reduced ductility. Beneficial effects from radiation to reactor cladding and structural materials are likely to be realized in the future when reactor designers take advantage of some of these changes.

TABLE 2—Radiation Effect of Properties of Various Alloys

	Rockwell hardness no.		*Yield strength (psi)*		*Tensile strength (psi)*		*Ratio of yield strength to tensile strength*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
28H14 aluminum	8F	40F	18,000	23,000	20,000	27,000	0.9	0.85
28O aluminum			7,000	17,000	17,300	26,000	0.51	0.65
High-purity iron			18,000	31,000	36,000	37,000	0.5	0.84
Normalized carbon steel			50,000	93,000	75,000	97,000	0.67	0.96
Hardened and tempered alloy steel			153,000	196,000	164,000	198,000	0.93	0.99
Austenitic stainless steel	81B	99B	37,000	97,000	98,000	115,000	0.38	0.84

Nonreactor Materials

Beneficial effects of radiation might become of practical usefulness in improving the properties of structural materials, semiconductors, and catalysts. Radiation-induced changes in the sensitive properties of semiconductors and catalysts seem to offer more promise than do changes in the structural properties of metals.

Neutron-irradiation of metals can increase hardness and tensile strength, usually without decreasing the ductility as much as in cold-rolling to achieve the same strength changes. Hardening can be done at low temperature and where mechanical working is not feasible.

Quicker response to electrical impulses, and changes in conductivities are among the radiation-induced beneficial changes that might prove of practical value in the semiconductor field. Radiation dosimeters based on the quantitative nature of the changes could become useful.

Structural materials. One area for utilizing the beneficial effects of radiation on metals lies in its use as a substitute for cold work to increase hardness and strength or as a means of producing age hardening in certain alloys.

As shown in Table 3, irradiation brings about a substantial increase in both tensile and yield strengths of a large number of aluminum alloys. While annealed material did show a decrease in ductility after irradiation, the loss was not as great as would be expected in alloys strengthened by cold rolling. Those alloys that were hardened by heat treatment or deformation prior to irradiation showed no loss of ductility. In some cases, a slight gain was observed. Age-hardenable nickel alloys (Hastelloy G and K Monel) can be irradiated with an actual increase in ductility.

While the effect of radiation on age-hardenable alloys has not been utilized to any extent, it does appear promising. It offers a method of hardening at low temperatures that may be used on special shapes or applications where conventional heating or mechanical working are not feasible. It should be realized that radiation hardening would be expensive and could be utilized only in special cases.

Semiconductors. Lattice defects produced by radiation change the characteristics of semiconductors because these defects influence the number and/or nature of the current carriers. For example, bombardment of an *n*-type germanium semiconductor with fast neutrons, alpha particles, or deuterons results in a decrease of electrical conductivity (*7*, *8*). Further irradiation produces a minimum in the conductivity versus radiation dose curve, followed by a conductivity increase on additional irradiation.

The conductivity minimum and the subsequent conductivity increase is interpreted as evidence for the formation of the *p*-type semiconductor. Irradiation of an *n*-type silicon semiconductor, however, does not convert it to the *p*-type. The effect of radiation on semiconductors, therefore, depends on the metal composing the semiconductor. In general, radiation effects in all semiconductor materials are annealed out completely only at high temperature. It may, therefore, be practical to produce semiconductors having different properties by exposing samples of a single type of semiconductor material to neutrons or charged particles for different periods of time.

The properties of semiconductors may also be changed by impurities produced by nuclear reactions with neutrons. This will be particularly important in very-high-purity semiconductors. In most semiconductor material, however, these impurities have only a small effect because of the much larger number of lattice defects produced by the radiation (*9*).

A specific example of a beneficial effect of radiation on a semiconductor is the improvement in the speed of response to electrical impulses reported for a semiconductor exposed to a fast-neutron flux (*10*). This change was apparently permanent and the current-voltage characteristics of the semiconductor were not changed by the radiation.

The quantitative radiation effects in semiconductors suggest their use as radiation dosimeters. Changes in the electrical properties of semiconductors also open up possibilities of using these materials to control electronic equipment in a radiation field.

Catalysts. The changes in structure and properties of metals produced

by radiation can affect their catalytic activity.

Most of the research on catalytic effects has been done with metal oxides because the radiation effects anneal out less rapidly than the effects in metals. Since many of the metals and metal oxides of catalytic interest show semiconductor behavior, there have been attempts to relate the radiation-induced changes in electrical properties of these materials to the change in catalytic properties. In general, metal oxides that exhibit *n*-type semiconductivity are catalysts for hydrogenation and dehydrogenation reactions. All oxides recognized as good hydrogenation catalysts are among these. The *p*-type oxide semiconductors show little or no catalytic activity for hydrogenation reactions.

There is little information available on the effects of radiation on the catalytic activity of metals. An early report showed that a platinum catalyst irradiated with X-rays gave better yields in the contact process for sulphuric acid production (*11*). The enhanced catalytic activity of the platinum decayed after the irradiation period, however.

Another example of enhanced catalytic activity in a pure metal is the reported effect of argon-ion bombardment in a single nickel crystal (*12*). Increased activity for hydrogenation of ethylene was observed. Since argon ions have little penetrating power, the increased catalytic effect in the nickel crystal is believed to have been a surface effect caused by radiation-induced defects in the nickel lattice.

Both positive and negative results have been observed for irradiated zinc oxide. A definite decrease in zinc oxide activity for hydrogenation of ethylene occurred on exposure to gamma rays from cobalt-60. On the other hand, low-energy X-rays had no effect on the catalytic activity of this oxide in the hydrogen-deuterium reaction.

From results obtained to date, it appears that some of the changes in sensitive properties of materials such as semiconductors and catalysts will have greater utility than changes in gross properties such as strength and ductility.

TABLE 3—Neutron-Irradiation Tests on Aluminum Alloys

*Material**	*Temper*	*Nominal composition (%)*						
		Mg	*Cu*	*Cr*	*Fe*	*Mn*	*Zn*	*Others*
1100 (2 S)	O—annealed	—	0.20	—	1.0	0.10	0.10	0.15
	H 14—strain hardened (half-hard)							
5052 (52 S)	O—annealed	2.50	0.10	0.25	0.45	0.10	0.10	0.15
	H 34—strain hardened and stabilized (half-hard)							
6061 (61 S)	O—annealed	1.00	0.27	0.35	0.70	0.15	0.20	0.15†
	T 6—solution annealed and aged							
5154 (A 54 S)	Cold reduced 50% in thickness	3.50	0.10	0.25	0.50	0.10	0.10	0.15

Material	*Condition*	*Number of tests*	*Yield strength, 0.2% offset (psi)*	*Tensile strength (psi)*	*Elongation, in 2 in. (%)*
1100-O	Control	8	6,800 ± 180	13,600 ± 320	38.2 ± 3.2
	Irradiated‡	25	17,100 ± 890	26,000 ± 2,000	21.2 ± 1.2
1100-H 14	Control	8	16,600 ± 250	17,300 ± 460	6.0 ± 0.6
	Irradiated	22	24,000 ± 450	26,000 ± 380	5.5 ± 1.2
5052-	Control	7	14,700 ± 670	29,200 ± 450	34.0 ± 3.4
	Irradiated	22	22,900 ± 540	37,400 ± 490	30.6 ± 4.2
5052-H 34	Control	7	29,500 ± 800	36,600 ± 700	11.2 ± 2.3
	Irradiated	21	36,400 ± 1,000	44,700 ± 1,200	14.0 ± 1.1
6061-O	Control	8	9,460 ± 200	18,050 ± 240	28.8 ± 2.8
	Irradiated	25	25,600 ± 460	37,300 ± 400	22.4 ± 0.8
6061-T 6	Control	8	38,500 ± 740	45,000 ± 320	17.5 ± 1.0
	Irradiated	23	44,400 ± 670	50,600 ± 540	16.2 ± 0.7
5154	Control	8	47,800 ± 450	54,700 ± 500	8.8 ± 1.1
	Irradiated	17	50,800 ± 460	57,800 ± 510	12.5 ± 0.6

* The first three specimens were 0.032 × 0.250 × 0.500-in. gage length; 5154 specimens were 0.062 in. thick.

† Also includes 0.60% silicon and 0.15% titanium.

‡ All samples were irradiated in the MTR at Arco, Idaho, for a total neutron irradiation of 1.26×10^{21} n/cm² with an estimated fast-neutron exposure of 1×10^{20} n/cm². Samples were water cooled to maintain a temperature around 150° F.

BIBLIOGRAPHY

1. D. S. Billington, in "International Conference on the Peaceful Uses of Atomic Energy," vol. 7, p. 421 (United Nations, New York, 1956)
2. C. E. Weber, *J. Metals* **8,** 651 (1956)
3. S. T. Konobeevsky, H. F. Pravdyuk, V. I. Kutaitsev, in reference **1,** p. 433
4. M. L. Bleiberg, L. J. Jones, B. Lustman, to be published in *J. App. Phys.*
5. R. V. Steele, W. P. Wallace, *Metal Progr.* **68,** 114 (1955)
6. J. C. Wilson, D. S. Billington, *J. Metals* **8,** 665 (1956)
7. K. Lark-Horowitz, E. Bleuler, R. E. Davis, D. Jendam, *Phys. Rev.* **73,** 1256 (1948)
8. R. E. Davis, W. E. Johnson, K. Lark-Horowitz, S. Siegel, *Phys. Rev.* **76,** 1255 (1948)
9. J. W. Cleland, J. H. Crawford, K. Lark-Horowitz, J. C. Pigg, F. W. Young, *Phys. Rev.* **86,** 961 (1951)
10. C. D. Florida, F. R. Hoet, J. N. Stephan, *Nature* **173,** 397 (1954)
11. G. L. Clark, P. C. McGrath, M. C. Johnson, *Proc. Nat. Acad. Sci.* **11,** 646 (1925)
12. H. E. Farnsworth, R. F. Woodcock, preprints of Symposium on Catalyst Preparation, American Chemical Society Division of Petroleum Chemistry, Dallas, p. 39 (1956)

Reprints

of this special report are available at $1.35 each from

Reprint Dept.

NUCLEONICS

330 W. 42nd St., New York, N. Y.

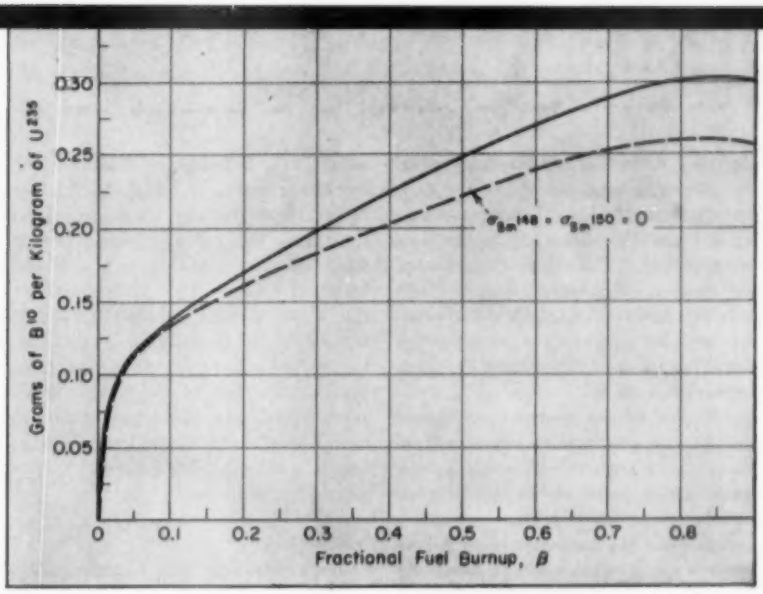


FIG. 1. Total fission-product poisoning as a function of fuel burnup using cross sections listed in the table. In lower curve Sm^{149} and Sm^{150} cross sections are assumed to be zero

Fission-Product Buildup in Enriched Thermal Reactors

Poisoning effects, important in long-burning reactors, can be evaluated readily with graphs given here. Better samarium cross-section data would reduce uncertainty

By ROBERT W. DEUTSCH
General Electric Co.
Knolls Atomic Power Laboratory
Schenectady, New York

FISSION-PRODUCT POISONING in reactors operating to large fuel burnup is extremely time-dependent because of the burnout of the higher cross-section isotopes. Since poisoning is of importance in the design of long-burning reactors, it is necessary to have an accurate description.

The equations governing stable-fission-product formation have been solved directly as a function of fractional fuel burnup for a reactor operating at constant volume.* Fission-product formation is expressed in terms of an equivalent B^{10} formation.

Such a representation is independent of the details of the reactor operation and only depends on the fuel burnup within the region. The stipulation of constant volume pertains to the volume being studied. It could include the entire reactor or only a section. It readily can be seen that for a reactor operating with a variable power distribution, the fission-product accumulation is a function of space and, if volumes with dissimilar loadings are being considered, an appropriate average should be made. This point will be discussed later.

Assumptions

By definition, a stable fission product is one that has a much higher probability of neutron capture than of natural radioactive decay, so that $\phi\sigma \gg (1/\tau_{1/2})$, where ϕ is the neutron flux, σ is the microscopic capture cross section, and $\tau_{1/2}$ is the half-life.

The effect of Xe^{135} is not included in these results. Assuming fluxes of 10^{14} neutrons/cm²/sec, Xe^{135} ($\sigma \sim 3 \times 10^6$ barns) *would* qualify as a stable fission product, even though it has only a 9.2-hr half-life. However, because a

* Poisoning in a thermal reactor by stable fission products has been evaluated for the special condition of constant fissionability or constant fuel replenishment (*1*). Such calculations are applicable to a reactor that converts nonfissionable material to fuel during its operation with the fission products continually increasing. However, it is not evident how to apply such results to a highly enriched reactor having an essentially zero conversion ratio.

lowering of the flux greatly changes the Xe poisoning and, since Xe^{135} has a resonance at 0.085 ev, the average cross section is very sensitive to the operating temperature and thermal spectrum of the reactor. Thus, the effect of Xe^{135} is both a function of an individual reactor and its operating characteristics and, for most calculations, is best treated separately.

All other fission products considered satisfy the stability criterion except that isotopes with half-lives of 2½ yr or longer are assumed stable regardless of how low their cross sections.

The effects of epithermal fission and capture are ignored. The calculations are performed for listed cross sections at neutron velocity of 2,200 m/sec. For the results to be valid at any other temperature for any thermal-neutron spectrum, the energy dependence of the fission-products cross section should be identical to U^{235}. Unfortunately, this is not the case, so that the actual fission-product accumulation is a function of the reactor operation, i.e., temperature and thermal spectrum. However, considering the uncertainties in both the yields and cross sections of fission products, greater detail is not warranted at present.

Calculations

The amount of a single stable fission-product, n_i, formed from U^{235} fission present at any time is determinable from its rate of change

$$\frac{dn_i}{dt} = \frac{y_i \phi n_U \sigma_U}{1.184} - \phi n_i \sigma_i \qquad (1)$$

The first term on the right side represents the number of fission products formed, and the second term represents the number burning out; y_i is the fission yield, ϕ is the thermal flux, n_U is the number of U^{235} atoms/cm³, $(\sigma_U/1.184)$ is the microscopic fission cross section, and σ_i is the microscopic fission-product absorption cross section.

For constant-power operation, the fuel is burning up linearly, so that for fractional burnup of fuel, β, up to any time T, the rate of uranium burnup is

$$\frac{dn_U}{dt} = -n_U \sigma_U \phi = -\frac{\beta}{T} n_{U_0}$$

where $\beta = (n_{U_0} - n_{U_T})/n_{U_0}$ and the subscripts 0 and T refer to the initial concentration and the concentration at time T.

Since

$$n_U = n_{U_0}\left(1 - \frac{\beta t}{T}\right)$$

then

$$\phi = \frac{\beta/T}{\sigma_U(1 - \beta t/T)}$$

Substituting these values into Eq. 1 gives

$$\frac{dn_i}{dt} + \frac{\sigma_i \beta/T}{\sigma_U(1 - \beta t/T)} n_i = \frac{y_i \beta n_{U_0}}{T(1.184)} \qquad (2)$$

Integrating Eq. 2 and evaluating at time $t = T$

$$\frac{n_i}{n_{U_0}} = \frac{y_i \sigma_U}{1.184(\sigma_U - \sigma_i)} [(1 - \beta)^{\sigma_i/\sigma_U} - (1 - \beta)] \qquad (3)$$

Although Eq. 3 has been derived for one specific mode of operation, it is completely general. It can be shown that operating at different power levels for various time intervals, that the accumulation of stable fission products is only a function of the total fuel burnup within a volume, and independent of the details of the operation.

Secondary, n_i', and tertiary, n_i'', fission products are formed by successive neutron captures. The equations governing their formation are

$$\frac{dn_i'}{dt} = n_i \sigma_i \phi - n_i' \sigma_i' \phi$$

$$\frac{dn_i''}{dt} = n_i' \sigma_i' \phi - n_i'' \sigma_i'' \phi$$

These equations can be solved for

Fission-Product Yields and Cross Sections

Nuclide	*Yield (%)*	*Cross section (barns)*	*Nuclide*	*Yield (%)*	*Cross section (barns)*
Se^{77}	0.02	40 ± 4	In^{115}	0.01	190 ± 10
Se^{79}	0.02	0.4 ± 0.4	Te^{126}	0.08	0.8 ± 0.2
Br^{79}	0.05	10.4 ± 1.0	I^{127}	0.21	6.7 ± 0.6
Se^{80}	0.07	0.59 ± 0.06	Te^{128}	0.52	0.3 ± 0.3
Br^{81}	0.18	2.6 ± 0.4	I^{129}	1.08	11 ± 4*
Se^{82}	0.46	2.0 ± 1.4	Te^{130}	1.88	0.5 ± 0.3
Kr^{83}	0.62	205 ± 10	Xe^{131}	3.00	120 ± 15
Kr^{84}	1.00	1 ± 1	Xe^{132}	4.47	2.5 ± 2.5
Kr^{86}	0.32	7.5 ± 7.5	Cs^{133}	6.74	29.0 ± 15
Rb^{85}	1.23	0.72 ± 0.15*	Xe^{134}	7.97	2.5 ± 2.5
Kr^{86}	2.25	1 ± 1	Cs^{135}	6.50	15 ± 8*
Rb^{87}	2.80	0.12 ± 0.03*	Xe^{136}	6.15	2.5 ± 2.5
Sr^{88}	3.64	0.005 ± 0.005*	Cs^{137}	6.15	1 ± 1*
Y^{89}	4.40	1.38 ± 0.14	Ba^{138}	6.36	0.68 ± 0.10
Sr^{90}	5.13	1.0 ± 0.6*	La^{139}	6.34	8.4 ± 1.7*
Zr^{91}	5.60	1.52 ± 0.12	Ce^{140}	6.23	0.63 ± 0.06
Zr^{92}	5.73	0.25 ± 0.12	Pr^{141}	6.00	11.2 ± 0.6
Zr^{93}	6.14	1.5 ± 3	Ce^{142}	5.68	1.8 ± 0.3
Zr^{94}	6.28	0.08 ± 0.06	Nd^{143}	5.35	280 ± 20
Mo^{95}	6.37	13.4 ± 1.3	Nd^{144}	4.75	4.5 ± 0.5
Zr^{96}	6.24	0.1 ± 0.1	Nd^{145}	4.00	52 ± 4
Mo^{97}	6.05	2.1 ± 0.7	Nd^{146}	3.15	9.2 ± 0.8
Mo^{98}	6.02	0.4 ± 0.4	Pm^{147}	2.35	60 ± 20*
Tc^{99}	8.00	19 ± 2	Sm^{147}	0.10	250 ± 250†
Mo^{100}	6.60	0.5 ± 0.5	Nd^{148}	1.85	3.2 ± 1.0
Ru^{101}	5.45	6 ± 6†	Sm^{149}	0.00	250 ± 250†
Ru^{102}	3.70	1.2 ± 0.3*	Sm^{149}	1.28	66,000 ± 2,500
Rh^{103}	2.40	150 ± 7	Nd^{150}	0.82	2.8 ± 1.5
Ru^{104}	1.70	0.7 ± 0.2*	Sm^{150}	0.00	250 ± 250†
Pd^{105}	0.75	9 ± 9†	Sm^{151}	0.49	12,000 ± 2,000
Pd^{106}	0.55	7.5 ± 7.5†	Sm^{152}	0.26	140 ± 40*
Pd^{107}	0.14	375 ± 375†	Eu^{153}	0.11	420 ± 100
Pd^{108}	0.05	12 ± 3*	Sm^{154}	0.05	5.5 ± 1.1*
Ag^{109}	0.02	84 ± 7	Gd^{155}	0.03	70,000 ± 20,000
Pd^{110}	0.02	0.3 ± 0.1*	Gd^{156}	0.03	375 ± 375†
Cd^{111}	0.01	300 ± 300†	Gd^{157}	0.02	160,000 ± 60,000
Cd^{113}	0.01	0.030 ± 0.015*	U^{238}	18.40	6 ± 2
Cd^{113}	0.01	20,800 ± 800			

* Activation cross section.
† Estimated range of cross section.

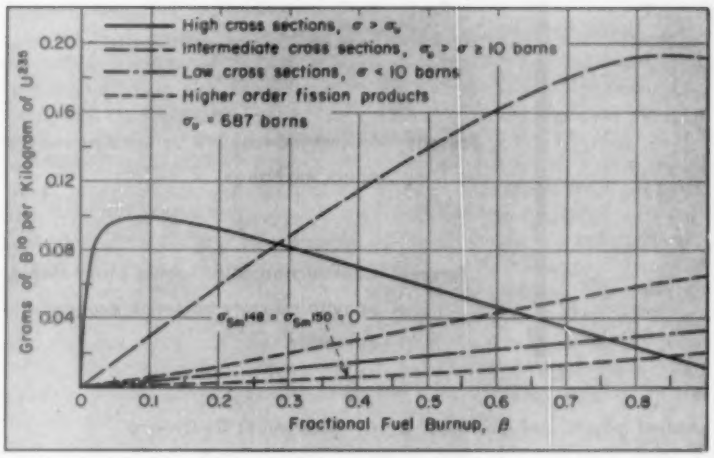


FIG. 2. Components of fission-product poisoning

n_i' and n_i'' by techniques appropriate to systems of linear differential equations.

The ratio of the total macroscopic fission-product cross section to the initial fuel cross section is the following for N fission products

$$\frac{\Sigma_{fp}(\beta)}{\Sigma_{U_0^{235}}} = \sum_i^N \frac{n_i\sigma_i + n_i'\sigma_i' + n_i''\sigma_i''}{n_{U_0}\sigma_U}$$

$$= \sum_i^N \frac{y_i}{1.184}\left[\frac{\sigma_i}{\sigma_U - \sigma_i}\right.$$

$$\left.\{(1-\beta)^{\sigma_i/\sigma_U} - (1-\beta)\}\right.$$

$$\left. + A_i(\beta) + B_i(\beta)\right]$$

where A_i and B_i are functions of β and the various cross sections.

Finally, converting the amount of fission products to equivalent amount of B^{10}, using $\sigma_U = 687$ barns and $\sigma_{B^{10}} = 4{,}000$ barns

$$\frac{M_{B^{10}}}{M_{U_0^{235}}}\left(\frac{\text{gm}}{\text{kg}}\right) = 7.31\,\frac{\Sigma_{fp}(\beta)}{\Sigma_{U_0^{235}}}$$

Yields and Cross Sections Used

The table gives the yields of fission products and the cross sections that have been used in these calculations; it includes the radiative capture in U^{235}. There is considerable fluctuation in the experimental values of the yields; tabulated values are those selected as giving the best fit to the present data (*1*).

The majority of cross sections are from BNL-325 (*2*). If total absorption cross section was not listed, the activation cross section was used. For isotopes with no cross-section information, a cross-section range is used that has been estimated by J. R. Stehn from experiments involving these isotopes. Also, certain recent measurements not listed in BNL-325 have been used. Zr^{93} and Tc^{99} have been measured to be 1.5 ± 3 and 19 ± 2 barns, respectively (*3*). Sm^{149} and Sm^{151} cross sections have been determined to be $66{,}000 \pm 2{,}500$ and $12{,}000 \pm 2{,}000$ barns, respectively (*4*).

Poisoning Results

Figure 1 shows the total fission-product poisoning as a function of fuel burnup using the cross sections in the table, as well as showing the effect of assuming the Sm^{148} and Sm^{150} cross sections to be zero. Figure 2 shows the individual components of the fission-product poisoning. The ordinate in Figs. 1 and 2 is the ratio of equivalent grams of B^{10} formed to kilograms of initial U^{235} loading.

For the high-cross-section poisons, it can be seen from Eq. 3 that for small fuel burnup, the poisoning is nearly independent of the cross section and proportional to the fission yield. Since a considerable spread exists in data on the yield of Sm^{149}, the prime source of initial poisoning, it determines the uncertainty for small burnups. For large fuel burnup, it is the lack of information of the Sm^{148} and Sm^{150} cross section that introduces the largest uncertainty. However, for purposes of most thermal reactor calculations using fully enriched fuel, the stable-fission-product poisoning is not a large effect. Thus, the uncertainties in yields and cross sections will not affect these calculations appreciably.

It is to be expected that fission products having high yields, as well as cross sections of the order of U^{235}, will be the most troublesome since the fission-product burnout is relatively small over most of the reactor life. In this connection, it is interesting to note that the individual isotope that contributes the most to the poisoning for large burnups (>40%) is Nd^{143}. On the other hand, Sm^{149} and Sm^{151} with their large cross sections reach a peak concentration quite early in the burnup (~10%), and for larger burnup there is a continual increase in the amount burned out relative to that formed. Thus, for large fuel burnups, Sm^{149} and Sm^{151} have a small effect, although Sm^{149} acts as a source of Sm^{150}. The reason for the large effect of Sm^{148} and Sm^{150} (assuming the 250 barns cross section) is the same that makes Nd^{143} such a prolific poison, and in addition, each isotope burns into the much higher cross-section Sm^{149} and Sm^{151}, which tends to double their effect.

As has been stated previously, fission-product poisoning has been calculated for constant volume. Thus, these results can be applied directly to any region in a multiregion calculation. However, since the poisoning is not linear with burnup, some care should be taken to average the poisoning correctly in analyzing a reactor in its entirety.

For example, for a reactor loaded uniformly, operating at fixed volume, the power distribution is not uniform, so the accumulation of fission products is space dependent. However, for this case, Fig. 1 very closely approximates the poisoning. Another example where averaging is necessary is a rod-controlled reactor operated at constant rod position for a large fuel burnup, and then operated with rods withdrawn, exposing a new fuel loading.

BIBLIOGRAPHY

1. W. L. Robb, J. B. Sampson, J. R. Stehn, J. K. Davidson, NUCLEONICS **13**, No. 12, 31 (1955)
2. D. J. Hughes, J. A. Harvey, BNL-325 (1955)
3. H. Pomerance, Oak Ridge National Laboratory, private communication
4. E. A. Melaika, M. J. Parker, J. A. Petruska, R. H. Tomlinson, *Can. J. Chem.*, **33**, 830 (1955)

Canadian Fuel Reprocessing

Past Early plutonium recovery used "trigly"-hexone-TTA solvent extraction

Present This was succeeded by more promising anion exchange

Future Construction of full-scale plant awaits enough reactors to permit economic operation

By W. M. CAMPBELL
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada

WHEN THE FIRST NUCLEAR REACTORS were being designed during the early part of the last decade it was realized that one major problem would be to recover fissile material from the irradiated fuel. This was a new field in chemical operations so it was natural that different development groups brought out different schemes, some of which have withstood the test of continued operation while others have fallen by the wayside. Although a number of papers have been written on U. S. experiences (*1–11*) the Canadian plants and processes have not been described. In this paper the processes that have been used at Chalk River up to the present time are reviewed, the fuels that will have to be processed in the immediate future are described and a brief summary is given of Canadian objectives in this field.

PAST—FIRST SEPARATION PROCESSES (1949–54)

Canada's first fuel-consuming reactor, the NRX, went into operation in 1947. By 1948 it was running routinely at 20 Mw. By late 1948 the first irradiated fuel was ready for processing.

Plutonium Recovery

Prior to 1948, development work on a plutonium-recovery process had been going on in laboratories in Ottawa and Montreal (this was before the Chalk River facilities were built). At an early stage in this work it was decided to use a solvent-extraction method; solvents were studied extensively.

Trigly extraction. In 1945 "trigly" (triethylene glycol dichloride—$ClCH_2CH_2OCH_2CH_2OCH_2CH_2Cl$) was selected. The reasons were:

1. In contact with a nitric acid solution of irradiated uranium and in the presence of a salting-out agent, plutonium has a higher partition coefficient than uranium and fission

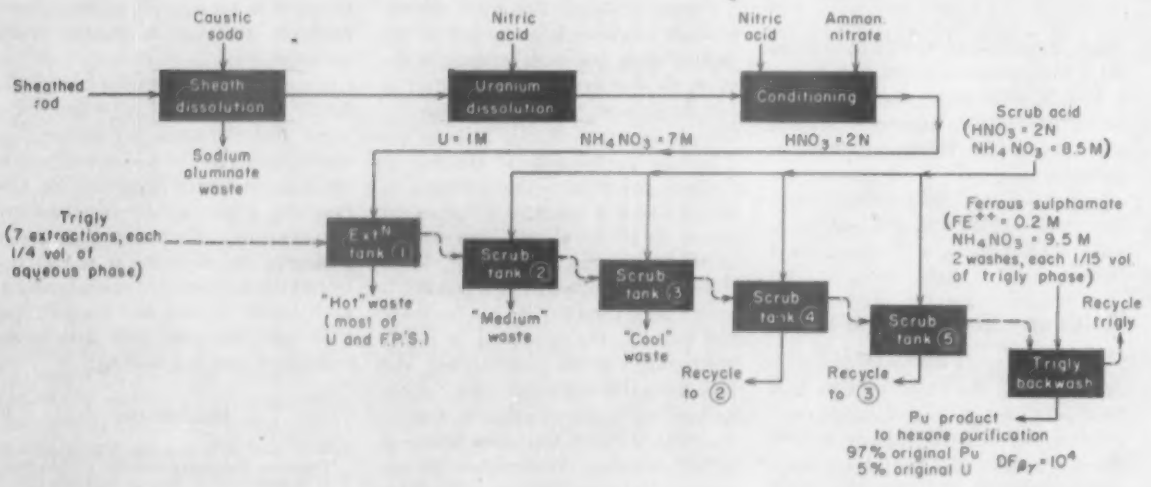


FIG. 1. Batch trigly process—first steps in early procedure for recovering plutonium from irradiated uranium fuel

products. This allows a selective extraction of plutonium into the trigly layer while leaving the bulk of the uranium and fission products behind.

2. Trigly is relatively stable in contact with strong nitric acid and it has a high flash point (250° F).

3. It worked satisfactorily in a batch-type extraction, which meant the laboratory work could be scaled up with a minimum of chemical engineering development.

Figure 1 shows a flowsheet of the trigly process (*12*). In this batch process the irradiated uranium, dissolved in nitric acid and conditioned with ammonium nitrate, was extracted seven times with trigly—the volume of each extraction being one-quarter the volume of the aqueous phase. Each trigly extract was scrubbed four times with $NH_4NO_3 + HNO_3$ solutions.

The combined extracts contained about 97% of the plutonium and 5% of the uranium with a fission-product decontamination factor of 10^4. The bulk of the uranium and fission products were left in the "hot" waste; minor amounts were in the other two.

Hexone-extraction purification. The next step in the plutonium-purification scheme was an oxidation-reduction cycle using hexone (methyl isobutyl ketone) as the extractant. This gave both uranium and fission-product decontamination. The flowsheet is shown in Fig. 2 (*12*).

Briefly, it consisted of extracting the aqueous trigly backwash solution, while still in the reduced state, with hexone to remove the uranium. The aqueous plutonium solution was then oxidized to convert the Pu^{III} to Pu^{VI}, which was then extracted with another lot of hexone. Backwashing of the solvent extract gave the hexone-purified product.

Final purification step. Finally the plutonium was purified by a TTA process using thenoyltrifluoracetone as the solvent. The flowsheet is shown in Fig. 3 (*13*).

The plutonium solution from the two previous processes was first precipitated as the fluoride to separate any organic-breakdown products. After dissolving the fluoride in $Al(NO_3)_3$ and HNO_3 and conditioning to 0.5*N* in HNO_3, the aqueous solution was extracted at 60° C three times with equal volumes of 0.5*M* TTA in benzene. The combined extracts were then washed with water to remove any of the dissolved or entrained aqueous phase, and the plutonium was backwashed with two small volumes of 10*N* HNO_3. After washing the combined aqueous phases with CCl_4 to remove any traces of TTA and benzene, the plutonium was precipitated with NaOH, redissolved in HNO_3, and the solution was evaporated to give the final plutonium product.

Modification of process. While the above processes operated smoothly, the continued use of ammonium nitrate was not favored—in stored waste it constitutes a serious explosion hazard. Other salting-out agents for the trigly stage were examined. Aluminum nitrate, zinc nitrate, etc., were satisfactory but they were undesirable from the waste-storage viewpoint since they would add large amounts of inert material.

Finally a scheme was worked out using uranyl nitrate as the salting-out agent, and with the scheme the existing trigly plant could be used although the operation was complicated. Next, to eliminate ammonium nitrate in the hexone process, this solvent was replaced by tributyl phosphate (TBP). The plutonium concentration step at the end of the TBP process was also changed from evaporation to precipitation, a change that gave a much cleaner feed to the TTA process and allowed the prefiltration and fluoride-precipitation steps to be dropped.

After these changes were made the three processes operated reasonably well. The plant was shut down in 1954 with the development of more promising processes. It is now being held in

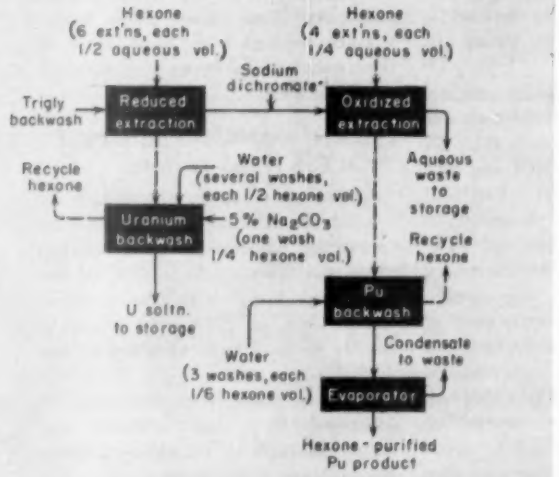


FIG. 2. Batch hexone process—further purification of trigly-processed plutonium. Product contains 40 gm/l Pu (97% of original), 10 gm/l U (0.03% of original), 10^4 cpm/ml βγ

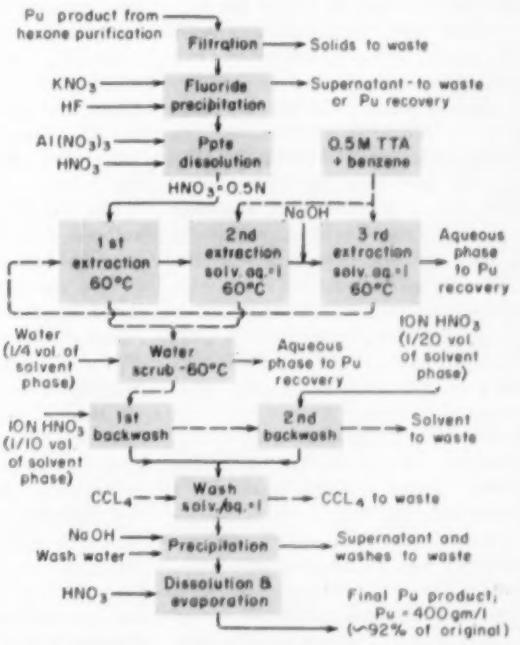


FIG. 3. Batch TTA process—final purification of hexone-processed plutonium

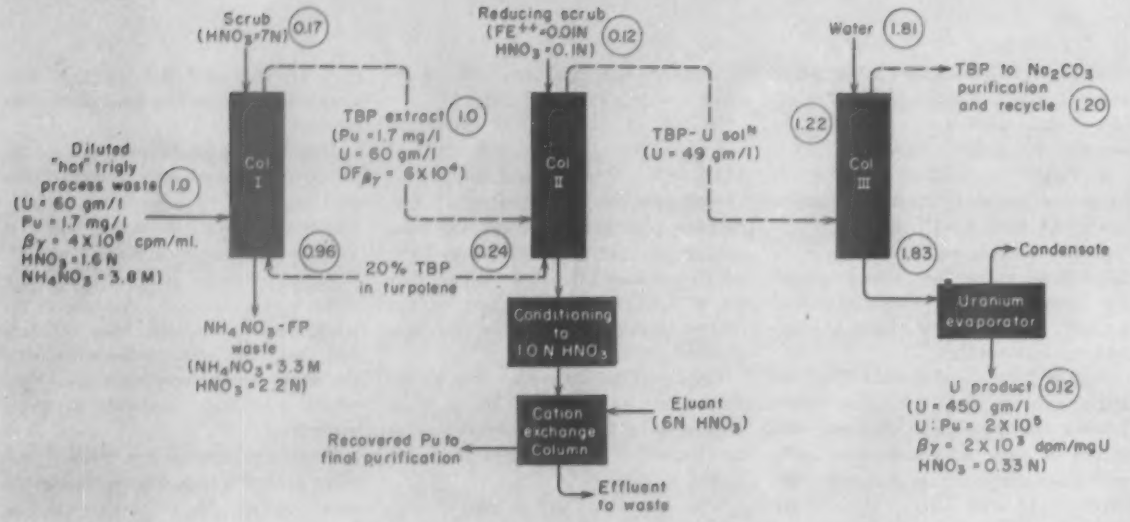


FIG. 4. TBP uranium-recovery process—uranium recovered from trigly-processed waste

standby condition although it is unlikely that it will ever be used again.

Uranium Recovery (1952 to date)

The "hot" waste stream from the trigly process contained most of the uranium and fission products with HNO_3 and NH_4NO_3. By 1951 there were 24,000 gallons of this waste (60 mg U/ml, 3.8*M* in NH_4NO_3) containing a total of about 70,000 lb of ammonium nitrate. This was considered a serious explosion hazard so development work on a disposal scheme was accelerated. The first step was to recover the U.

A TBP (tributyl phosphate) process (*14*), shown in Fig. 4, was worked out and a plant capable of recovering 200 lb of uranium per day was put into operation in 1952. In this process the uranium-fission product solution is fed into the middle of the first column. TBP diluted with an inert kerosene-type diluent rises countercurrent to the aqueous stream and extracts the plutonium and uranium. The extract solution then goes to the second column where a reducing aqueous stream extracts the plutonium leaving the uranium in the solvent. In the third column the uranium is backwashed out of the TBP phase with water. The plutonium leaving the bottom of the second column is concentrated by a cation exchange cycle.

Due to the limited development time available, packed columns were used. Thus the number of stages per column is low and the separations are not as good as might be obtained with more efficient contactors. Most of the plutonium in the wastes is recovered pure enough to go directly to a final purification step, but the uranium does not quite meet the target specification for plutonium (Pu:U of $1:10^7$) or for fission-product activity (0.3 millicuries per kg of uranium).

Ammonium Nitrate Destruction (1953–4)

The above process left the ammonium nitrate with the HNO_3 and the fission products. Several methods of NH_4NO_3 destruction were examined and finally the HCl-HNO_3 method was selected for two reasons, (a) the flowsheet and equipment were simple although it was realized that severe corrosion problems would have to be solved and (b) the fission products would be left in solution and thus would be easier to handle later. The flowsheet is shown in Fig. 5 (*15*).

The NH_4NO_3-HNO_3 fission-product raffinate from column 1 of the uranium-recovery process was made 0.1*N* in Cl^- by the addition of HCl and was then fed to the decomposer. Feed and evaporation rates were balanced to give a constant liquid hold-up. The condensate was re-evaporated to reduce the activity going out in this stream. After five days of continuous running with continuous fission-product buildup in the decomposer the feed was replaced first with 0.1 HCl in 2.5*N* HNO_3 and then with water to reduce the residual NH_4NO_3 and Cl^-, respectively. Further concentration was done and then the concentrate was drawn off to storage.

All the NH_4NO_3 was destroyed by this process. Although the process worked smoothly the corrosion troubles in the glass-lined equipment were severe. Most of the corrosion was on the decomposer and evaporator lids, which carried all the connecting lines.

Once this operation was finished and the concentrated fission products stored in a HNO_3 solution, it marked the end of the first fuel-processing phase at Chalk River.

The plants used for the above processes were direct-maintenance plants, remotely operated as required. The earlier plants were designed with steam ejectors, splitter boxes, etc., instead of pumps, valves, and the more conventional type of chemical equipment. Now that more experience has been gained with maintenance in high-level fields more of these conventional types of equipment are being used.

PRESENT—ANION-EXCHANGE PROCESS (1955 to date)

Several years ago development work started on an anion-exchange process to recover plutonium from irradiated uranium. This work is now in the pilot-plant stage with the commissioning late in 1955 of a plant to handle about 100 lb of uranium per day.

In this plant the plutonium is separated from the uranium and fission products by an anion-exchange resin (Dowex-1, 8% crosslinked). The flowsheet is shown in Fig. 6.

The dissolver solution is first conditioned to 7.5*N* in nitric acid and is

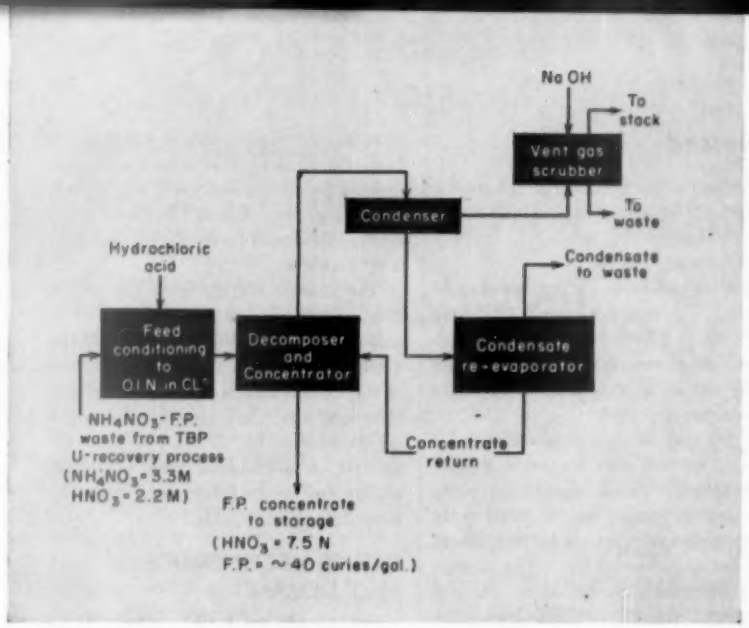

NaOH
To stack
Vent gas scrubber
To waste
Condenser
Condensate to waste
Hydrochloric acid
Feed conditioning to 0.1 N in Cl⁻
Decomposer and Concentrator
Condensate re-evaporator
NH_4NO_3-F.P. waste from TBP U-recovery process (NH_4NO_3 = 3.3M HNO_3 = 2.2M)
Concentrate return
F.P. concentrate to storage (HNO_3 = 7.5 N F.P. = ~40 curies/gal.)

FIG. 5. Process for destruction of ammonium nitrate remaining in waste from TBP uranium recovery

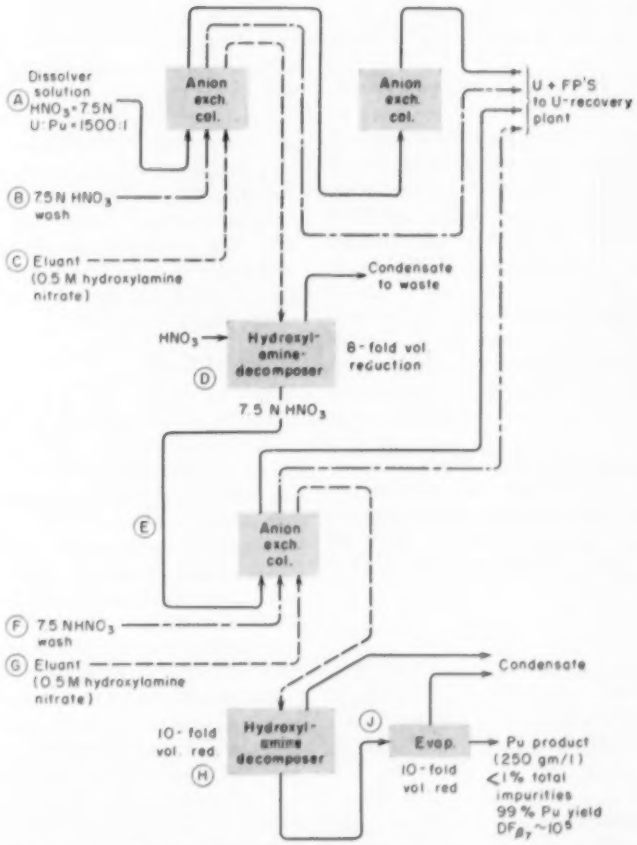


FIG. 6. Current anion-exchange process for plutonium recovery. Uranium is later recovered in TBP process (A to J is sequence of operations)

then passed to the first-cycle resin columns (8-in. diameter, 39 in. high), two of which are connected in series.

The resin in the columns rests on a plate of grade C sintered, stainless steel. Above the resin bed there is a 1-in. layer of glass wool and on top of this a perforated lead weight encased in stainless steel. This serves to keep the resin compressed and allows for some expansion and contraction during the cycles. Above the lead weight is another sintered stainless-steel disk, which traps any resin particles that escape from the bed.

The plutonium is absorbed on the columns while the uranium-fission-product solution passes through at a rate of 0.75 ml/min/cm^2. The uranium is later recovered in the TBP uranium-recovery plant described earlier.

With a U:Pu ratio of 1,500:1 the resin capacity is about 2 mg Pu/ml of resin. When the first column is saturated it is disconnected from the system, washed with 7.5*N* nitric acid to remove the uranium and fission products, and the plutonium is then eluted with hydroxylamine nitrate solution. The eluant is evaporated 8-fold, and by keeping the acid in the pot up to 7.5*N* the hydroxylamine is destroyed at the same time.

A second cycle (4-in.-diameter, 36-in.-high column) is carried out to purify the plutonium further. The two cycles only give a β-γ decontamination factor of about 10^5, so some further treatment will be necessary. This has not been completely worked out yet.

Another unknown that has not been evaluated on a plant scale is resin life. To date the two columns in the first cycle have separated about 800 gm of plutonium from uranium rods irradiated to 700 Mwd/ton and cooled for six months to one year. This is equivalent to a resin consumption of 70 ml per gram of plutonium, but the columns have not deteriorated noticeably and are still being used.

Waste Disposal

The main fission-product wastes, essentially free from uranium and plutonium, are concentrated by evaporation to a volume of less than 1 gal/100 lb of uranium processed. They are then stored in underground stainless-steel tanks. The wastes are left acidic (12*N* in HNO_3), since the extra solids that would have to be added to neutralize them might make any future perma-

Present and Future Fuels to Be Processed

At present Canada has one reactor, NRX, producing fuel for processing. A second reactor, NRU, is in the final construction stages, and a third one, NPD, the first power reactor, is expected to be operating in 1959.

In NRX three fuels are being irradiated and require processing:

1. *Natural uranium irradiated to as high a level as possible. The amount to be processed will be less than about one ton per month. The rods are round, 10 ft long by 1.36 in. in diameter, and are sheathed in aluminum. Each rod contains 120 lb (54.5 kg) of uranium, and after the average irradiation it contains 48 gm plutonium and about 80 gm of fission products. A cooling period of 6 months is normally allowed before processing, currently by the anion-exchange process.*

2. *Plutonium-aluminum alloy. Some fuel of this type is used to compensate for neutron losses due to experimental irradiations. The rods have the same over-all dimensions as the uranium rods described above, but the core design is still undergoing development. In one design the plutonium concentration varies from the center to the end with a maximum in the center. Rods of this type have been irradiated until about 55% of the total plutonium (78% of the Pu^{239}) has been burned up. The over-all composition of the irradiated rod is about 5 kg of aluminum (including the sheath), 150 gm of plutonium, and 185 gm of fission products. One such rod has been satisfactorily processed to date in the anion-exchange plant.*

3. *Thorium, irradiated in the outer regions of the reactor. In the past thorium has been irradiated as the oxide, and the irradiations were stopped when the U^{233} content was about 0.1 gm/kg of thorium. The fission-product content was very low. This fuel was processed by a batch solvent-extraction process using diethyl dithiocarbonate dissolved in hexone. This was followed by a differential carbonate separation and an anion-exchange step to purify the U^{233}. All the thorium now being irradiated is in the metallic form, and while it is expected that the irradiations can be carried much further the limit has not been determined. The processing of this metallic fuel will not start until late 1957 or early 1958. It is unlikely that the existing process can be used with the much higher fission-product activity.*

The second major reactor at Chalk River, NRU, is a 200-Mw (thermal) reactor. The principal NRU fuel will be natural uranium flats, 10 ft long by about 3/16 in. thick by 1¾ in. wide, sheathed in aluminum. It is expected that the first uranium will be ready for processing late in 1957. Some thorium metal rods (1.65 in. dia. × 10 ft long) also will be irradiated in the outer regions. Since better cooling for the thorium is provided than in NRX it is expected that the irradiations will be longer and the rods will not be processed until they contain about 2 gm U^{233} and about 0.2 gm fission products per kg of thorium. The first thorium fuel from NRU will not be ready for processing before about the end of 1958.

Canada's first power reactor, NPD, is a small unit of about 20,000 kw (electrical) capacity. It is being designed and is expected to be in operation by 1959. The fuel will be either natural uranium metal or oxide sheathed in Zircalloy or an aluminum alloy. The irradiation is expected to be of the order of 3,000 Mwd/ton. But it is hoped that the level can be much higher. By late 1959 fuel from this reactor will be ready for processing.

The fuels for Canadian power reactors that will be designed in the future are uncertain, but as long as natural uranium and plutonium are the only fuels available, the types described above probably will be used. Thus, the present thinking in Canada is that future power-reactor fuels will be some combination of U, UO_2, Pu, PuO_2, Th and ThO_2, either pure or mixed with some metal such as aluminum, and sheathed in Zircalloy or preferably in an aluminum alloy.

---

nent-waste-disposal scheme more difficult.

Other acid wastes having relatively low activity (10^6 cpm β/ml) are evaporated, mixed with cement, and the mixture is poured into steel drums. After the cement sets, the drums are stacked in a pit on a concrete pad, and then concrete is poured around the stack producing a large concrete block about 10 × 10 × 6 ft. The first disposal of this type was made in late 1955, so it is too early to assess it from a health standpoint.

The very dilute wastes, such as from laboratories, the laundry, etc., are pumped into the ground in a disposal area about 1¼ miles from the Project. Several lots of more active wastes have been dumped in this area for experimental purposes, but until a complete study of ground disposal has been made this method will be used only for very dilute wastes.

The caustic wastes from the aluminum-sheath dissolutions are stored in underground tanks where some precipitate separates out carrying with it most of the Pu and fission products. Present data indicate that the clear overflow probably can be discharged into the ground in a disposal area while the sludge can be transferred to stainless-steel drums and buried.

FUTURE—ECONOMICS AND DEMAND

During the next 10-yr period there will only be a few reactors operating in Canada, and consequently the amount of fuel processing to be done will be small. For example, by the early 1960's the amount of irradiated uranium to be processed from NRX, NRU and NPD probably will be less than 100 ton/yr. The amount of enriched plutonium fuel and thorium will be negligible by comparison since these reactors will use natural uranium mainly. This quantity is much below the minimum for economic processing. Thus any processing done during this period will be to gain experience, to try out process improvements, and to collect cost data. Private industry eventually may take over fuel processing, so this interim period also will give the interested companies a chance to study the operation before taking on the job.

Effect of Cost

The amount of fuel processing required by a large power reactor depends on the irradiation the uranium can take. If the average irradiation goes up to say 6,000 Mwd/ton, the fuel cost for a once-through, heavy-water, natural-uranium reactor may be acceptable. Under these conditions the uranium would not be recycled and the plutonium would only be returned to the reactor if its cost as fuel were less than that of fresh natural uranium.

It seems likely that on a large-enough scale plutonium can be separated from irradiated uranium by the TBP process and can be recycled at a lower cost than natural uranium, but there are many economic and experimental studies to be completed before this is known definitely.

Canadian Power Demand

The demand for nuclear power in Canada will grow slowly and it may be many years before it will reach 1,000,000 kw—the estimated load that is needed for reasonably cheap fuel processing. Thus, it may be uneconomic to process fuel during this initial growth period. This difficulty can be overcome by designing the first few reactors as once-through reactors, and storing the spent fuel until such time as an economic processing plant is justified. The stored fuels would then be processed along with the currently produced fuels and from then on the reactors would use recycled plutonium as well as natural uranium.

Chalk River Program

Meanwhile economic studies and fuel preparation and processing development will continue at Chalk River. The TBP separation process for irradiated fuels is cheap and well understood. However, for the immediate future, three phases of the over-all processing scheme will command primary attention in the Canadian development program.

The first of these is feed preparation (dissolving, conditioning, etc.) for the newer alloy and ceramic fuels that are being studied.

The second is waste disposal, since as yet no permanent method of disposing of the main bulk of the fission products has been accepted generally. One scheme currently being studied at Chalk River is disposal in glass; at present the results are very encouraging.

The third phase is the development of a small cheap plant that will allow processing to be economic even in the early stages of nuclear power expansion.

BIBLIOGRAPHY

1. S. Lawroski in "International Conference on the Peaceful Uses of Atomic Energy," Vol. 9, paper P/823 (United Nations, New York, 1956)
2. F. L. Culler, *ibid.*, Vol. 9, paper P/822
3. J. R. Flanary, F. L. Culler, *ibid.*, Vol. 9, paper P/539
4. A. T. Gresky, *ibid.*, Vol. 9, paper P/540
5. F. L. Culler, F. R. Bruce, *ibid.*, Vol. 9, paper P/541
6. E. E. Motta, *ibid.*, Vol. 9, paper P/542
7. H. M. Feder, *ibid.*, Vol. 9, paper P/544
8. A. F. Voight, *ibid.*, Vol. 9, paper P/545
9. H. H. Hyman, *et al.*, *ibid.*, Vol. 9, paper P/546
10. O. E. Dwyer, *et al.*, *ibid.*, Vol. 9, paper P/550
11. D. E. Ferguson, *ibid.*, Vol. 9, paper P/551
12. D. D. Stewart, National Research Council of Canada, Division of Atomic Energy, Report No. CPP-2 (1950)
13. I. A. W. Morrison, Atomic Energy of Canada Ltd., Report No. I.O.I. 17 (1952)
14. H. K. Rae, S. H. Russell, Atomic Energy of Canada Ltd., Report No. C.E.I.-46 (1952)
15. E. E. Winter, Atomic Energy of Canada Ltd., Report No. XM-72 (1952)

New methods point toward . . .

Cheaper Ways to Make D_2O

Cheaper D_2O may result from new processes like distillation of liquid hydrogen and dual-temperature hydrogen-water exchange catalyzed by HCl. A striking new possibility is the use of radiation to catalyze exchange reactions or produce H_2 from natural gas

By PAUL HARTECK
Chemistry Department
Rensselaer Polytechnic Inst., Troy, N. Y.

NUCLEAR DEVELOPMENTS in recent times have increased the demand for heavy water. More D_2O production at lower costs is required if the potential of heavy-water-moderated reactors is to be exploited fully. Some possible processes for producing heavy water at lower cost will be outlined after a brief discussion of the demand and the over-all economics of heavy-water production.

Price and Demand

Construction of research reactors and power plants using heavy water as moderator will greatly expand the market for heavy water (*1*). Just how much will depend on its price. With heavy water priced less than \$40/lb,* nuclear power plants on a heavy-water base become economically promising and might compete with other designs. If the price of heavy water could be dropped lower than \$10/lb, its price would be relatively insignificant.

* At the Geneva Conference the price at which the United States government will sell heavy water was quoted at \$28/lb. The basis for the calculation of this price was not disclosed, however.

The total U. S. need of heavy water in the near future has been estimated to be between a few hundred and 1,000 tons per year (*2*). These estimates have been made under the assumption of normal power expansion, with a reasonable part using heavy-water reactors.

With the new demands for heavy water, new methods of production have been investigated, some of which have been developed and used.

Over-All Considerations

In discussing the production of heavy water, a number of factors must be considered: size of the units, parasitic methods, independent methods, high concentration enrichment, and possible new methods.

Size of units. An economic plant for the production of heavy water must have a yearly production of at least 30 tons/yr, or 1 gm/sec. There is 1 gm of heavy water in about 6.5 kg of water; hence, if a process removed 20% of the heavy water, about 10 gal/sec of fresh water must enter and leave the system to produce 1 gm/sec of D_2O. This means 300-million gallons of feed water per year. This gives a rough idea of the size of such an installation.

Judging from the demand for heavy water, units not smaller than 30–100 tons/yr should be built. From cost

analysis it can be shown that this is also the size where the price for D_2O is almost independent of plant size.

Parasitic methods. In industry there are processes operated for purposes other than the production of heavy water that can also be used to make D_2O. An example is the electrolytic production of hydrogen for the ammonia synthesis. The electrolytic plant of the Norsk-Hydro in Norway obtains a large amount of heavy water as a by-product from an operating electrolytic plant at a cost of almost nothing. The additional costs are for the high-concentration stage, the handling of deuterium, administration, etc. The industry claims that the high cost arises from the fact that the total plant is no longer flexible while producing heavy water as a by-product.

Actually, of the large amount of hydrogen used in the production of ammonia, far less is made electrolytically than is made by means of the water-gas process. One of the new methods to be discussed later looks to the use of water-gas hydrogen as the ingredient in a new parasitic method.

Independent methods. When there arose in the U. S. during World War II a sudden need for heavy water, there was no time for development, and within reasonable limits, cost could be disregarded. Under these conditions the fractional distillation of normal water was used. The cost of heavy water by distillation of normal water was $160/lb (3). Even with refinements it appears that the price for heavy water could not be dropped under $50 using this method. Some foreign countries that are not able to spend large sums of money for development and that have waste natural gas or geothermal steam may be interested in a water-distilling plant for its D_2O production, especially if they prefer an independent supply.

To build and run an electrolytic plant to produce D_2O is much too expensive. Only when the hydrogen is used for other purposes and heavy water is a by-product is the combination economic. For example, an electrolytic plant with 100,000 kw power can produce 5–10 tons D_2O/yr. The price of D_2O would be about $450/lb ($D_2O$ not being a by-product) taking into consideration only the price for the electric energy and handling cost.

New direct methods will be considered later.

Early D_2O Production Processes

In 1941, distillation, chemical exchange, and electrolysis techniques were considered to be the only ones readily applicable to separating large quantities of the hydrogen isotopes for the nuclear program.

A process involving catalytic exchange of deuterium between H_2 gas and H_2O vapor was used because of its straightforwardness and the availability of electrolytic hydrogen at the NH_3-synthesis plant of the Consolidated Mining and Smelting Co. at Trail, B. C.

The new process began operating in June, 1943. In four stages, 2,200 lb/day of 2.3% D_2O were produced; final concentration of 1,100 lb of D_2O per month took place in a three-stage electrolytic plant. Total cost of modifying the Trail plant to include D_2O production came to about $2.6-million, $200,000 of which was for development. Incremental operating cost averaged less than $30,000/mo, 20% of which was for the electrolytic portion. A prorated charge of 30% later was added for electricity and labor. D_2O from Trail now costs over $60/lb.

Because it uses standard fractional-distillation methods, the water-distillation process was used in plants built at the Morgantown Ordnance Works (W. Va.), Alabama Ordnance Works, and Wabash River Ordnance Works (Ind.). In continuous eight-stage vacuum-distillation trains, these plants concentrated the water to about 90% D_2O; final separation was done in batches in an electrolytic finishing plant built at Morgantown. First shipments were made from the $14.5-million plants in January, 1944; until later improvements were made, the distillation plants produced 2,536 lb of 90% D_2O per month. Monthly total operating costs of $423,000 made each pound of pure D_2O cost about $200 (3).

High-concentration enrichment. Frequently one method is used to enrich the deuterium to about 2 to 20%, and a second to concentrate the D_2 to 99.8% or more. Obviously, it is important that the method used for the first step be as economical as possible, and that the method for the second step be primarily a dependable method for making pure heavy water. The high-concentration step should not be too expensive, but it is more important that it be highly dependable, because the total energy consumption for the high concentration is minor compared with the energy consumption for the first enrichment. But, if the high-concentration step does not work properly, total production is stopped.

Furthermore, production flow sheets show it is important that the method used in the high-concentration stage should have a high separation factor. Therefore, for the high-concentration steps the electrolytic method is very favorable. In a continuous process, a series of 10–15 cells are necessary to produce almost pure D_2O starting from water with about 20% D content. In a batch process only one or two cells are necessary. As a high-concentration step, only one electrolytic unit, combined with a rectifier for liquefied hydrogen, would be excellent because this combination has a separation factor as large as necessary.

New Methods

Advances in heavy-water production in the future probably will be in the modification and improvement of present systems, rather than in developing any entirely new process. However, these improvements may incorporate the combination of several systems to yield a more economical over-all process.

Any new method necessarily must compete with methods known and used today. Most present methods are designed to minimize the amount of energy needed. Therefore, any new system would have to be of a similar nature with low energy costs.

Some specific possibilities follow.

Use water-gas hydrogen. As indicated in the discussion of parasitic methods, most of the hydrogen used in ammonia synthesis is produced by the water-gas method. This hydrogen has about the normal deuterium content or slightly less.*

* Water-gas hydrogen normally is very carefully cleaned because impurities like sulfur compounds would contaminate the ammonia catalyzer, but there may be small amounts of residual argon or nitrogen because these gases would not do any harm to the ammonia synthesis.

1. *Parasitic.* It is known that in the thermodynamic equilibrium at room temperature of the system HD + $H_2O \leftrightarrow H_2$ + HDO there is about four times as much deuterium in the water than in the hydrogen. With increasing temperature, equilibrium nears unity. Thus, if the hydrogen produced from the water-gas process could be given in the kinetic exchange equilibrium with water at room temperature or temperatures below 100° C, water could be produced in which the deuterium is enriched by a factor 3–3.5 compared with normal water. The yield of heavy water produced from such starting water similarly would be 3–3.5 times that produced with a start from normal water, and the additional costs would come only from the exchange process.

2. *Direct.* Another way to use this water-gas hydrogen would be to liquefy the hydrogen and, by means of fractional distillation of this hydrogen, pure or highly enriched HD or D_2 could be produced and burned to D_2O. In recent years the distillation of liquid hydrogen has been considered very seriously. Fourteen years ago, when K. Clusius first suggested this method, large-scale hydrogen liquefaction was not as developed as it is at the present time.

The big advantage of a hydrogen-liquefaction unit is the very high separation factor: it is possible to produce practically pure HD in one step starting from normal D concentration (1:6,500) or even less. However, impurities like nitrogen and argon, which freeze out during the process of liquefaction, can cause some difficulty.

Dual-temperature exchange. A very promising direct method is dual-temperature exchange. The principle of this method is the chemical exchange of deuterium between two immiscible substances at two different temperatures in counterflow. The equilibrium coefficient, and thus the distribution of deuterium in the two phases, varies with the temperature. At the high temperature the deuterium will tend to concentrate more in one phase and at the low temperature it will be transferred to the second phase. As the deuterium is exchanged back and forth in large exchange towers, a concentration gradient occurs between the top and bottom of the towers (*4*).

The advantage of this method is that there is almost no waste in substances. In some systems there is no step where a large amount of energy is consumed as in a distilling column or in an electrolysis plant. However, in a liquid-liquid exchange system the substances involved are corrosive, because only substances that rapidly exchange deuterium with water can be used, and these are obviously either acids or bases.

In this, as in all phases of heavy-water production, there may have been considerable effort expended in development work in different countries, but since almost nothing is published, it is hard to estimate if or how far these methods are developed.

In discussing the parasitic methods, we mentioned the distillation of hydrogen, when the hydrogen was produced for other purposes. However, a plant could also be built that works independently on the basis that hydrogen becomes liquefied, the HD fractionated, and the depleted hydrogen regenerated by catalytic exchange with normal water at high temperatures. However, such regeneration is a rather expensive step, and even at higher temperatures the equilibrium is unfavorable because there is always less deuterium in the hydrogen than in water.

Dual-temperature exchange using hydrogen and water. One possible improved method would involve the dual-temperature exchange system using hydrogen and water. Both substances are cheap, noncorrosive, and have almost the highest separation factor known. However, the exchange of deuterium between hydrogen and water is extremely slow and even with a catalyst the rate is high enough only at temperatures above room temperature.

Ionizing radiation that would produce hydrogen and deuterium atoms could be used under special conditions to catalyze the exchange, via the reactions

$$\left.\begin{aligned} H + HDO &\rightarrow D + H_2O \\ D + H_2O &\rightarrow H + HDO \end{aligned}\right\} \sim 12 \text{ kcal activation energy}$$

$$\left.\begin{aligned} H + HD &\rightarrow H_2 + D \\ D + H_2 &\rightarrow HD + H \end{aligned}\right\} \sim 7 \text{ kcal activation energy}$$

HCl-catalyzed exchange. Even at high temperatures the exchange would still be slow because of the magnitude of the activation energy. However, the exchange might be improved by the addition of a small amount of HCl to the gas stream. The exchange would then occur according to

$$\left.\begin{aligned} H + HCl &\rightarrow H_2 + Cl \\ D + HCl &\rightarrow HD + Cl \\ Cl + H_2 &\rightarrow HCl + H \\ Cl + HD &\rightarrow HCl + D \end{aligned}\right\} \begin{matrix}\text{gas phase:} \\ \sim 4\text{–}5 \text{ kcal} \\ \text{activation} \\ \text{energy}\end{matrix}$$

$$HCl + HDO \rightarrow DCl + H_2O \text{ (liquid phase; no activation energy)}$$

With the lower activation energy, the reaction is much faster. About 300 kw of ionizing radiation absorbed in the gas phase should equilibrate the deuterium exchange of 10^4 moles/sec of water and hydrogen. This new method of exchange can be combined into a process to make an economical method for producing about 100 tons/yr of D_2O.

Use of radiation. Along the same idea, a mixture of hydrogen and water could be equilibrated by ionizing radiation at 300° C or higher without HCl. The deuterium could be removed from the hydrogen stream by the rectification of the liquid hydrogen. The depleted hydrogen then could be recycled, with fresh water, through the ionizing radiation to regenerate it once more to a concentration of about 1:10,000 compared to 1:6,500 in normal hydrogen. This method would make a large supply of hydrogen unnecessary for the liquefication.

In the not too distant future, large amounts of hydrogen might be produced from natural gas directly by the impact of fission products. This hydrogen can be made very pure because hydrocarbons, including methane, can be removed easily and thus be suitable for rectification.

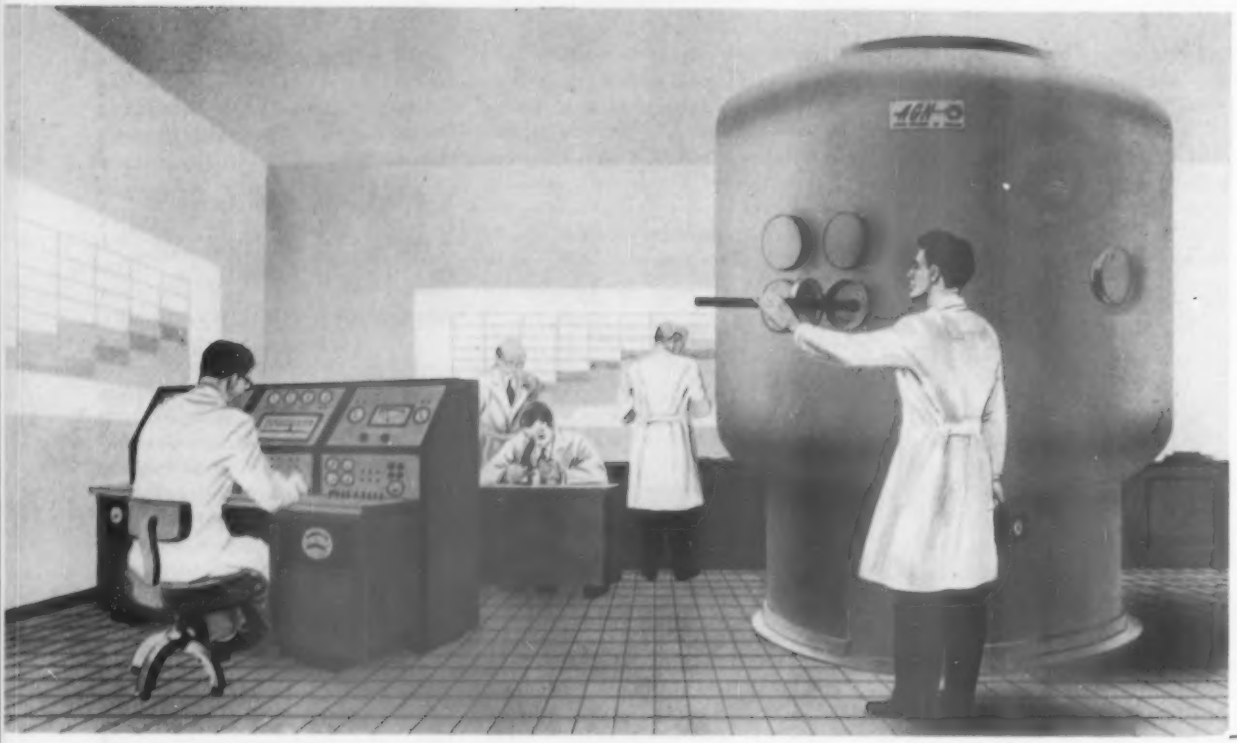
It is rather interesting to note that the development of nuclear and ra diation chemistry may supply tools for the production of deuterium.

* * *

I appreciate very much the hélpful criticism of my paper on heavy water production by P. J. Selak and J. Finke, and further discussions with R. Reeves of the RPI research staff.

BIBLIOGRAPHY

1. Heavy water production, NUCLEONICS **13,** No. 9, 64 (1955)
2. "A growth survey of the atomic industry 1955–56," (Atomic Industrial Forum, Inc., New York, 1955)
3. P. J. Selak, F. Finke, Heavy water, *Chem. Eng. Progress* **50,** 221 (1954)
4. "Production of Heavy Water," G. M. Murphy, Ed., National Nuclear Energy Series, III-4F (McGraw-Hill Book Co., New York, 1956)



Compact, Low-Cost Reactor

For use in education, medicine, and industry, this 100-mw system consists of a 9½-ft-high reactor unit and remote control console. Installation in existing buildings requires no extra shielding

By A. T. BIEHL, R. FAYRAM, R. HENLEY, G. A. LINENBERGER, H. MONTGOMERY, R. MAINHARDT, G. NEWBY, J. RANDALL, D. SAWLE, and J. SHERWIN
Aerojet-General Nucleonics, Subsidiary of Aerojet-General Corporation, San Ramon, California

A SMALL RESEARCH reactor, the AGN-201, is designed for use in education, research, medical diagnosis, and industrial process control. It is especially intended for applications in which high thermal-neutron flux is not necessary but low cost, maximum safety, portability, and high sensitivity are required. Its basic characteristics are shown in the table on p. 101.

The reactor and control units are shown in Fig. 1. The two are connected together by a cable. Shielding is designed to prevent overexposure of personnel even in the unlikely event of an accidental power surge. Additional safety features include power and reactivity monitors to operate a scram mechanism and a fuse that will cause the core to separate in case of a power surge.

Purposes

In designing the AGN-201, the objectives were to make the reactor as safe and foolproof as possible, to use a minimum of uranium no more than 20% enriched (for export purposes), to provide adequate in-pile exposure volume with a thermal-neutron flux as high as possible per unit of power, to make it as small, light, and inexpensive as possible, to provide an effectively infinite life, and to provide a high analytical sensitivity for danger-coefficient tests.

ENGINEERING DESIGN

Within certain constraints, the AGN-

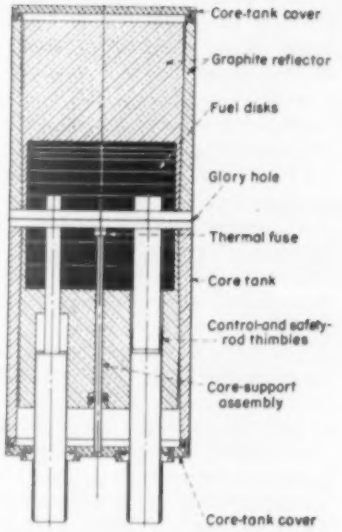


FIG. 2. Core tank contains uranium-polyethylene core, safety fuse, and portions of graphite reflector

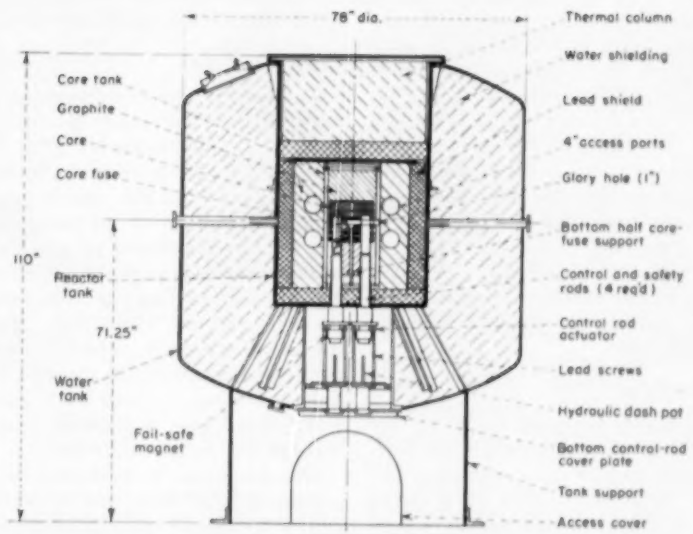


FIG. 3. Reactor unit contains core, reflector, lead shield, and borated-water shield. Control and safety rods are inserted from the bottom

Emphasizes Safety

201 is a minimum-critical-mass reactor. Its critical mass is estimated as 600 gm of U^{235} in the form of 20%-enriched UO_2. It is contained in the form of a powder dispersed in a solid polyethylene moderator. No sacrifice in safety has been made to lower the amount of U^{235} required.

The theoretically smallest critical mass of U^{235} is estimated to be under 300 gm. Such a design would use a polyethylene moderator and a thick, high-density BeO reflector. Containers, control rods, etc., would increase the critical mass. A design of this type was considered, but it was discarded because of health hazards and high cost associated with handling of BeO. A thin high-density graphite moderator replaces the BeO.

Characteristics of the AGN-201 Reactor

Power, licensed	100 mw
Power, with special provisions	3 watts
Maximum thermal flux (100 mw)	4.5×10^8 n/cm²/sec
Critical mass	3,000 gm of U (20% enriched)
Core size (cylinder)	10 in. dia, 9½ in. high
Moderator	11 kgm polyethylene
Impregnation density (U^{235})	50 mg/cm³
Reflector (graphite)	20 cm thick (1.70 gm/cm³)
Shield (lead)	10 cm thick (7,500 lb)
(water with 3% HBO_3)	55 cm thick (8,700 lb)
Over-all diameter	6½ ft
Over-all height	9 ft
Over-all weight of reactor unit	22,000 lb
—with water shielding drained	13,300 lb
Temperature coefficient of reactivity	-3.6×10^{-4}/°C

Thermal Neutron Flux

Since the thermal neutron flux of any reactor is nearly proportional to power divided by critical mass, minimizing the critical mass for safety reasons also provides the maximal neutron flux for any given power and fission-product accumulation.

Size and Weight

The problem of size and weight of the AGN-201 depends almost entirely on the shielding to prevent radiation overexposure to personnel in a power

surge. Thus more than enough is provided for normal operation at 100 mw. Shield design is determined by estimates of the maximum conceivable accident. This is estimated as 2×10^8 joules for a 2% step change in reactivity. The maximal dose limit for personnel just outside the shield during such an accident has been chosen as 1 rem, the equivalent of three weeks at the "maximal permissible level" as established by the USAEC. With the establishment of these parameters it is then possible to design a minimal-weight shield.

Core Life

Sufficient evidence exists on the effects of ionizing radiation on polyethylene to allow a fair estimate of core life. Experiments show there should not be noticeable dimensional changes or foaming at doses less than 1,000 Mrep (10^{11} ergs/gm). Assuming that 10% of the fission energy appears as ionizing radiation in the polyethylene, the dose rate at 100 mw (10^8 ergs/sec) is about 3 Mrep/yr. Thus the core has an estimated minimal life of 300 yr at a 100-mw power level (24 hours a day, 7 days a week). The fuel burnup is almost inconsequential, amounting to some 30 μgm/yr. Thus there appears to be no fundamental reason why a very long life can not be expected.

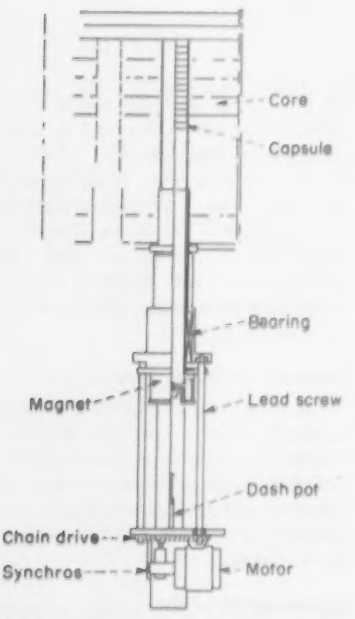


FIG. 4. Control rod is driven by reversible motor through lead-screw coupling. Active length is 15 cm. Fuel is enclosed in two aluminum containers to provide double fluid-tight seal

Core Design

To facilitate core construction and assembly, the core is made in nine sections of various thicknesses (Fig. 2). The thinner sections allow varying the amount of U^{235} in the core in small enough increments for adequate control of the critical mass for assembly and experimental purposes. Each of the four bottom disks has three 5-cm-dia holes and one 2.5-cm hole. Two are for safety rods; one is for the coarse control rod; and the small one is for the fine control rod. A horizontal "glory hole," about 1 in. in diameter, passes through the center of the reactor.

The core disks are formed from a mixture of polyethylene and UO_2 in the form of 10–20-micron-dia UO_2 particles. The total density of UO_2 is then 284 mg/cm³, yielding a weight ratio of 1 gm of UO_2 to 3.16 gm of polyethylene.

Neutron source. A 10-mc Ra-Be source is located in the graphite reflector to supply neutrons on startup. With safety rods cocked and control rods all the way out, the multiplication of the reactor is sufficient to generate 30 μw of power and give indications on all instruments. Thus the reactor power can be safely varied by a factor of 3,000 (0.030–100 mw) by use of the control rods.

Reflector, lead shield. The reflector consists of 20 cm of high-density graphite (1.70 gm/cm³) on all sides of the core (Fig. 3). Appropriate holes are provided for the glory hole, safety and control rods, and access ports. Both core and graphite reflector are surrounded by 10 cm of lead shielding. The reflector weighs about 750 lb, and the lead shield weighs about 6,300 lb.

Access ports. A total of four access ports plus the glory hole and a thermal column are provided for experimental work. The four access ports (4-in. dia) pass completely through the reflector. The glory hole (1 in. dia) passes completely through the core. Under normal operating conditions all ports are filled with appropriate plugs or stringers to match surrounding materials.

Fluid-Tight Tanks

As shown in Fig. 3, three concentric fluid-tight tanks surround the core. They are designated, respectively, the core tank, the reactor tank, and the water tank.

Core tank. The core tank has been designed to contain any fission gases given off by the core. Commercial alloyed aluminum is the structural material throughout. The tank has upper and lower sections, separated by an aluminum disk passing through the main cylinder in the same plane as the glory hole. This disk separates the core into two parts and is part of the safety-fuse system. Detachable top and bottom cover plates, as well as control- and safety-rod thimbles, form an integral part of the tank.

The lower section of the core tank contains half of the core material as well as a two-piece cylindrical section of graphite reflector. These pieces of core material and the inner piece of graphite reflector are supported by an aluminum rod projecting downward from a fuse link supported from the bottom cover plate. Ample space at the bottom of the cylinder is provided to insure free fall of the bottom half of the core-plus-reflector section when the fuse melts in any accidental power surge. This fall is further facilitated by a graphite-to-graphite taper joint that insures against binding.

The upper section of the core tank is filled with six sections of core. A space for core expansion and gas accumulation is provided in the top of the tank.

Reactor tank. The lead shielding, reflector, and core are enclosed in and supported by a thick steel tank of 43.4-cm radius. It has a removable top cover to permit access to the core tank. This tank acts as a secondary container for the core-tank assembly and, with the glory hole and access ports closed, is completely fluid-tight.

Water tank. The water tank is the third and outermost of the fluid-tight containers. This main structural member is 6½ ft in diameter and constructed of steel. Access can be gained to the top of the core assembly, even with water in the water tank, by removing the top cover plate and thermal-column tank. The fast-neutron water shield in the water tank consists of about 1,000 gal of water containing 250 lb of dissolved boric acid.

The upper or "thermal-column" tank serves as a shield when it is filled with water and lead or as a thermal column when it is filled with graphite. It is removable to allow taking out either the cover of the core tank or the core tank itself.[1]

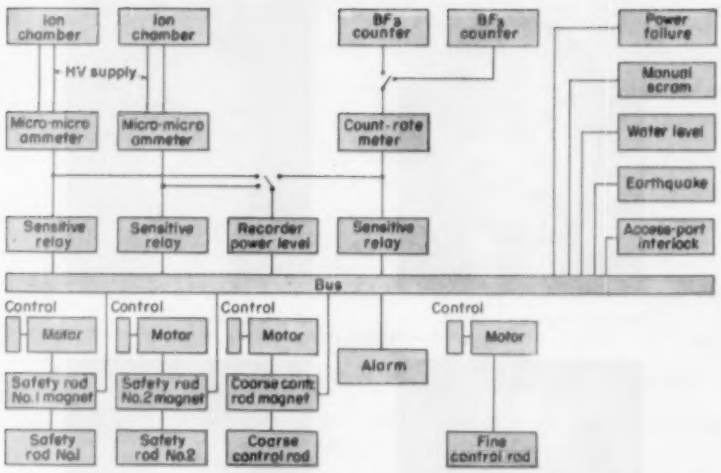


FIG. 5. Control system has two boron ion chambers and BF_3 proportional counter for power-level monitors. Micromicroammeter amplifiers connect ion chambers to relay-and-recorder system. BF_3 counter is connected through counting-rate meter to relay system. Relays can be set to scram reactor at any predetermined power level

Safety and Control Rods

The AGN-201 reactor has two safety rods and two control rods. The two safety rods and the coarse control rod are identical. The fine control rod is similar but has half the diameter of the others. Each rod contains 0–20 gm of U^{235} and operates so that reactivity is increased as the rod is inserted. The amount of reactivity each rod controls increases as the amount of active material contained increases. With the maximum of U^{235} in the coarse rods (13.3 gm at 50 mg/cm³) each rod controls about 1.6% reactivity. The fine control rod has been adjusted to control about 0.2% reactivity.

Figure 4 shows the design of the control rod. The active fuel in the rod is enclosed in two aluminum containers. The outermost container provides the fluid seal with the core tank, and the innermost one seals the active fuel in the rod. By this design a double fluid-tight seal is maintained for the core and for control and safety rods.

Control and safety rods also serve another purpose. They provide a means of obtaining a fine adjustment of the uranium in the core, offering a convenient method of adding or removing small amounts of fuel. They are designed for use in critical experiments during startup as well as for small adjustments in available reactivity under normal operating conditions.

Safety-rod operation. The safety rods are in the safe or subcritical position when they are out. In this position the active fuel in the rod is just inside the lead shield. The rods are inserted one at a time by a drive mechanism requiring about 1 min to travel the full 25-cm stroke. The release mechanism is constructed so that if a scram signal is received at any time, the three large rods are driven to their outermost positions.

The safety system is a fail-safe design. The scram signal opens the direct-pull holding magnets allowing the rods to be accelerated outward by both gravity and compressed springs. The spring constant is such that the rods are initially accelerated with a force of 5 g, requiring a total withdrawal time of 140 msec. The reactivity change of both safety rods is 0.9% during the first 50 msec. The rods are decelerated by a hydraulic dashpot in the last 12.5 cm of travel.

Control-rod operation. Reversible d-c motors drive both coarse and fine control rods through lead-screw assemblies. The motors are controlled by switches at the control console. At maximum speed of travel the coarse rod causes a reactivity change of about $3 \times 10^{-4}\,\text{sec}^{-1}$. Positions of both control rods are indicated remotely at the control console. Interlocks prevent control-rod movement unless the safety rods are "cocked." The safety rods cannot be cocked until the control rods have reached their safe or starting positions.

Control Console

The control system is very similar to that used for other low-power reactors. It is shown schematically in Fig. 5. Scrams are initiated by a power failure, an earthquake detector, a water-shield-level detector, low-temperature detectors, a manual scram button, optional access-port interlocks, and the power-level monitor.

It can be seen from Fig. 5 that the recorder can be switched to monitor any of the neutron-detection devices. Both ion chambers are located just outside the lead shield in the borated-water neutron shield. The BF_3 counter is just outside the lead shield in the region occupied by control and safety rods.

In the event of a scram, any one of the three detectors or other safety devices actuates the scram system causing automatic and rapid ejection of both the safety rods and the control rods, and operation of both warning light and bell.

Safety

The system is designed to minimize the possibility of a nuclear runaway, and, in the event of such an excursion, to protect personnel from excessive radiation. Time constants of the scram system may not be such as to stop a fast excursion before thermal expansion of the core would catch it. On the other hand, careful analysis shows that such self-limiting does prevent liberation of a dangerous amount of energy. The action of the core fuse (made of polystyrene containing 100 mgm/cm³ of U^{235}) and the safety rods then insures against a repetition of the same accident. The core fuse will heat faster than the core and melt at 100° C.

Fission products will be contained for the most part in the core. Since this is made of polyethylene cross-linked by radiation, it will not melt at anticipated temperatures. If all the fission products created in the greatest conceivable accident were liberated in a room of 10^6-liter capacity, estimates indicate that the level of the most dangerous isotope, I^{131}, would be just barely at a dangerous level.

* * *

The authors acknowledge the early conceptual contributions of North American Aviation, Inc., and the Applied Radiation Corp. for their evaluations of similar low-power research reactors.

The Japanese Atomic Energy Commission

Hideki Yukawa

Hiromi Arisawa

Matsutaro Shoriki (chmn)

Ichiro Ishikawa

Yoshio Fujioka

JAPAN

Speeds Organization of Nuclear Program

By CLARK GOODMAN
U. S. Atomic Energy Commission
Washington, D. C.

THIS IS A REPORT *on the rapid development of nuclear affairs in Japan since last year's Geneva conference. One of the author's major observations is that the Japanese government is taking the lead in research while Japanese industry is taking the lead in power developments. This turn of events is in the tradition of strong industrial leadership in Japan. The Japanese Atomic Industrial Forum provides the focal point for industry.*

However, the main activity is in the individual large companies, particularly the leading utilities such as Tokyo Electric Power and Showa Electric in Tokyo, Kansai Electric Power in Osaka, and Kyushu Electric in Fukuoka. Each of these companies has an active study group whose objective is to determine as quickly as possible which nuclear power system is best suited to the environment and economy of Japan.

- **Japan is more prosperous now than in 1954 or 1955.**
- **Nuclear energy has become an accepted reality to the Japanese people.**
- **Nuclear energy has become a major means of international cooperation and negotiation between Japan and other countries.**
- **Nuclear energy is being used both individually and collectively as a powerful political propellant in Japanese academic, industrial, and government circles.**
- **Since the atomic energy law of Japan went into effect (Jan. 1, 1956), her atomic activities are being rapidly and effectively organized.**
- **As part of this effort a broad base is being established in nuclear science and engineering.**
- **The major leadership in nuclear research is being taken by the government.**
- **The major leadership in nuclear power development is being taken by private industry.**
- **The present delicate political balance in Japan, more than any other single factor, will probably delay somewhat the development of industrial nuclear power.**

THE FUTURE INDUSTRIALIZATION of Japan, as in the past, will be directly proportional to the additional power capability that can be built and operated economically. The present power generation operates at an unusually high load factor. In some cases operation is certainly beyond the optimum economic level since there is no time for systematic repair and replacement.

It is true that the 8–9-million kw of developed hydropower represents only about 40% of the national potential. However, the cost of construction and operation will increase markedly as the more marginal watersheds are utilized. Somewhere, at some as yet undeterminable point along this rising cost curve, nuclear power will become competitive with hydroelectric power.

Japan's 5–6-million kw of chemically-fueled electric power are supplied largely by her domestic coal production, which totals 40–50-million tons per year. Modernization of mining methods has offset to some extent the increase in cost of coal production. Japanese nuclear power at first will face stiff competition from Japanese coal even though it is high in ash content. However, in the long run industrial nuclear power will exceed chemical power because of the limited coal reserves.

The annual production of about 2.2-million barrels of petroleum only provides less than 10% of Japan's domestic needs. Hence, more than 90% of her crude oil is imported so as to keep the ever-increasing number of internal combustion engines supplied with gasoline and diesel oil. The U. S. produces as much petroleum in one day as Japan does in three years. Yet the population of Japan is more than half that of the U. S.

To plan and execute the bringing of nuclear power to Japan, a complete organization has been evolved.

Japanese Atomic Organization

The atomic energy law of Japan, which became effective in January this year, establishes the following five organizations:

1. Atomic Energy Committee (reports to the prime minister through the chairman, Matsutaro Shoriki, who is a state minister in the Cabinet).

Members (two full-time, two part-time, appointed by prime minister with consent of both houses of Diet):

Ichiro Ishikawa (also chairman of board of directors of the Atomic Research Institute), full-time.

Yoshio Fujioka (formerly professor of physics at Tokyo University), full-time.

Hideki Yukawa (Nobel Laureate in physics and professor at Kyoto University) part-time.

Hiromi Arisawa (professor of economics at Tokyo University) part-time.

2. Atomic Energy Bureau (administrative agency to carry out general administrative functions of JAEC), Toshitake Sasaki, director. Divided into three sections: general affairs, isotope, and administration.

3. Atomic Energy Research Institute (supported primarily by the government and in part by industry).

Ichiro Ishikawa, chairman of board of directors.

Sakuji Komagata, vice chairman (an electrical engineer, formerly director of electrotechnical laboratory of the Ministry of International Trade and Industry—MITI).

4. Joint Diet Committee on Atomic Energy.

Yasuhiro Nakasone, chairman (member of House of Representatives, Liberal Democratic Party).

5. Nuclear Fuel Corporation (responsible for the prospecting, mining, refining and controlling of nuclear raw materials and nuclear fuel materials). Just being formed—chairman not yet named.

In addition, the following are im-

The author, who had spent a year in Japan in 1954–55, visited Japan again this year sponsored by the International Educational Exchange Service, Department of State. About half his time was spent in traveling and giving lectures on the general status of industrial nuclear power in the United States. The other half was used in detailed discussions with Japanese scientists, engineers, industrialists and government officials regarding the present status of nuclear energy developments in Japan. This report summarizes the observations made during this trip.

portant segments of the atomic organization.

6. Japan Atomic Industrial Forum (established March 1, 1956, as a private organization of about 300 companies having interest in atomic energy development; information-exchange and money-raising are primary functions). Executive members:

President—Reinosuke Suga, chairman, board of directors of the Tokyo Electric Power Company.

Vice presidents—Kineo Uemura, vice-chairman, Federation of Economic Organizations; Atsushi Oya, chairman, fuel committee, Federation of Economic Organizations; Michisuke Sugi, chairman, Osaka Chamber of Commerce and Industry.

Managing directors—Naritaro Okamatsu, director, Japan Chamber of Commerce and Industry; Teizo Horikoshi, secretary, Federation of Economic Organizations; Soichi Matsune, director, Federation of Electric Power Companies; Seinosuke Hashimoto, director, Institute for Electric Power Economy.

Secretary General—Seinosuke Hashimoto, director, Institute for Electric Power Economy.

7. Nuclear Research Institute (an essentially independent unit of Tokyo University).

Seishi Kikuchi, director.

Since the national universities derive their primary research support from the Japanese government, the Nuclear Research Institute is financed almost entirely from government appropriations. After some initial difficulties in getting started because of local inhabitants' fear of stray radiation, this well-equipped laboratory for basic physical research has been established at Tanashi, about 25 miles from the center of Tokyo. A 60-in. cyclotron (alternatively a synchro- or fixed-frequency cyclotron) is being built. Plans are well advanced for a 600-Mev electron synchrotron. Some consideration is being given to a 2-Bev proton synchrotron, but this is well in the future. This laboratory is undoubtedly the best equipped and most effectively organized of any scientific laboratory in Japan. The equipment is all new and of the latest type. Budgeting is no longer a difficulty. Housing of the staff remains the only pressing problem since Tanashi is only a small village.

8. Nuclear Laboratory at Osaka University. While at Osaka University, Kikuchi, now director of the Nuclear Research Institute, built up a strong experimental physics group that is continuing actively under Tetsuo Wakatsuki. A 15-Mev cyclotron is operating with a good outside beam. A 3-Mev pressurized Van de Graaff is being used effectively by Kenzo Sugimoto for angular correlation studies during electric excitation of nuclei by protons. A 20-Mev betatron is being used to produce X-rays for radiography. This work is part of the general program of applied physics being carried out under the direction of Tsunejiro Asada. Other important basic physics researches in progress at Osaka University are high-resolution beta-ray spectroscopy, high-resolution low-intensity mass spectrometry and X-ray crystallography (under Prof. Watanabe).

K. Fushimi has for the past two years been active in promoting nuclear engineering in Japan. His efforts have resulted in the translation of several books into Japanese—notably Glasstone and Edlund's "Elementary Reactor Theory." He has also built up one of the more knowledgeable groups of young enthusiasts. Most of these young men are located at other institutions.

9. Kyoto Laboratory of Nuclear Science. Under the direction of Prof. Kimura, a 16-Mev fixed-frequency cyclotron has been completed recently.

This machine will be used for physics experiments and for production of radioisotopes. Concurrent with the recent work on the cyclotron, some staff members carried out detailed studies of fallout and radioactive fish. These researches have been reported in detail in a publication that has received wide distribution in the U. S.*

A small plant ($28,000) for producing D_2O by an evaporation method went into operation earlier this year. The estimated cost of D_2O is $50/lb, i.e., about twice the U. S. sales price.

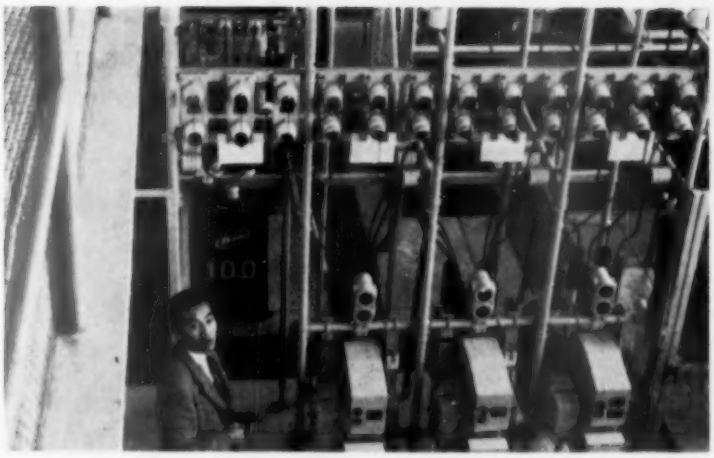
Several of the younger staff members, notably Sakae Shimizu and Dr. Okada, have begun actively promoting a research reactor of the swimming-pool type. The University of Michigan has generously provided a set of blueprints of their Phoenix Project reactor and buildings. These plans are much more elaborate than Kyoto expects to be able to build to, but they form an excellent starting point for their study.

10. Research Institute for Fundamental Physics. This Institute, known as Yukawa Hall, is the apex of science in Japan, being headed by Hideki Yukawa, Nobel Laureate in physics. Despite his membership on the Japanese Atomic Energy Commission, it is doubtful that any appreciable amount of the theoretical research at this Institute will be devoted to applied atomic energy. However, a symposium was held on nuclear fusion in May, 1956.

11. Tokyo University. The nuclear laboratory has a 3-Mev Van de Graaff and a 4-Mev cyclotron. In addition, much basic and applied nuclear physics is done. In fact, Tokyo University is the most outstanding educational institution in Japan. It is only because of my lack of detailed knowledge about this University that much more is not

* Reviewed in NUCLEONICS, April '55, p. 86.

MORE THAN 350,000 persons saw U. S. Information Agency's Atoms-for-Peace show in Tokyo before it went on tour of Osaka, Hiroshima, Fukuoka, Sapporo, and Sendai. Show had spectacular success in Japan; said one review, "It replaced the vague and menacing picture of the 'atomic mushroom' with a shining vision of a happier, healthier, more prosperous mankind . . . "



SEISHI KIKUCHI in new Nuclear Research Institute lab at Tanashi near Tokyo

included here regarding its place among the atomic organizations in Japan.

12. Radiochemistry Laboratory. This well-equipped and ultramodern laboratory is part of the school of chemistry at Shizuoka University. It is headed by Takanobu Shiobawa, a recognized authority on the separation and study of radioactive ash. In particular he has studied in detail the materials from the *Fukuryu Maru* —the fishing boat "Fortunate Dragon" that was caught in fallout from a U. S. bomb test. His well-equipped laboratory is also active in radioactivity monitoring.

13. Meteorological Research Institute. This institution has extensive monitoring equipment for rain, seawater, air, and dust. Under the direction of Yasuo Miyake, detailed studies of low-activity fallout are carried out on a continuous basis. Detailed studies of the Russian tests have been made and indications of the test sites have been obtained and published.

14. Other nuclear research facilities are: (a) Tokyo Education University; a 3–5-Mev betatron; a larger betatron is planned. (b) Tokyo Technological University; a 40-Mev synchrotron. (c) The Science Research Institute (Tokyo); a 4-Mev cyclotron and cosmic-ray research facility.

Japan-U. S. Bilateral Agreement

The research bilateral agreement between Japan and the U. S. was made on June 21, 1955, and signed in Washington on Nov. 14, 1955. On March 12, 1956, a contract was made between the Atomic Energy Research Institute (AERI), under authorization of the Japanese government, and North American Aviation, Inc. (Atomics International Div.) for the purchase of a 50-kw water-boiler (type L-8) research reactor (containing about 1.5 kg U^{235}). Thus Japan became one of the first four countries to sign a contract for a research reactor pursuant to a U. S. bilateral research agreement. I think this step epitomizes the present active interest of the Japanese in this field.

The second research reactor to be located at the AERI site will be of the CP-5 type. It was originally planned that this would be 100 kw (heat). The latest plans call for raising this to 5,000 kw so as to attain a maximum neutron flux of 10^{14} and to be able to use the reactor for radiation testing (i.e., as a small-scale MTR). This reactor will contain enriched uranium and will be purchased from a U. S. company. The AERI hopes to have this reactor installed in 1957.

Atomic Energy Budget

The total amount budgeted for fiscal 1954 and 1955 for the Japanese atomic energy program was about $1.7-million. The amount budgeted for fiscal 1956 is about $10-million—mostly to the AERI and for training of nuclear scientists and engineers. Further, AERI expects to receive about $0.5–$0.6-million in contributions from industry —largely through their Forum.

In addition, most of the major electric companies have their own nuclear research groups, as do a number of the large industrial companies. No budget figures for these were available.

Radioisotopes

Applications of radioisotopes in medical and agricultural fields have been carried out in Japan for many years. Applications in industrial fields have been expanding rapidly in the last few years. At present the imports of radioisotopes (largely from the USAEC) aggregate $100,000/yr.

The Kyoto cyclotron will begin to supplement these pile-produced isotopes soon. However, in the future, the research reactors being installed will take over most of the radioisotope production in Japan. Because of foreign currency restrictions, domestic radioisotopes will probably be used in preference to imported ones even though the latter may be somewhat less expensive dollarwise.

Future Power Demands

The power requirement in Japan has increased about 9%/yr during the last several years. According to their 5-year economic program, it is estimated that power requirements will average an increase of 6.3% until 1960. Beyond 1960 the forecast, while less certain, seems to decrease down to 5 to 4% increase in requirement per year. Thus, it is estimated that Japan's power requirements will be doubled in 15 years and multiply 2.5 times in 20 years. To meet such future requirements it is necessary to continue to develop about a million kw of electrical capacity annually, while the exploitation of Japan's hydro and coal resources is reaching the limit.

The total potential hydropower resources officially estimated is 22-million kw. Major economical sites will be mostly developed in 15 to 20 years if the development continues at the present rate. Coal-fired power is considered to reach its limits, physically as well as economically, in 10 years.

Hence, it is considered necessary in Japan that power demonstration reactors be built within a few years so as to realize economical nuclear power as early as possible. In this way the Japanese hope to be supplying part of their power requirements by means of large nuclear plants by 1966.

The Japanese AEC is even now considering a British proposal that allegedly would give them economic nuclear power in five years (NU, July '56, p. R5, Aug. p. R6), and is sending study teams to both the U. S. and U. K. this fall.

A Gamma-Discriminating Beta Survey Meter

By WALTER F. JOSEPH and RICHARD M. BOND
U. S. Naval Radiological Defense Laboratory
San Francisco, California

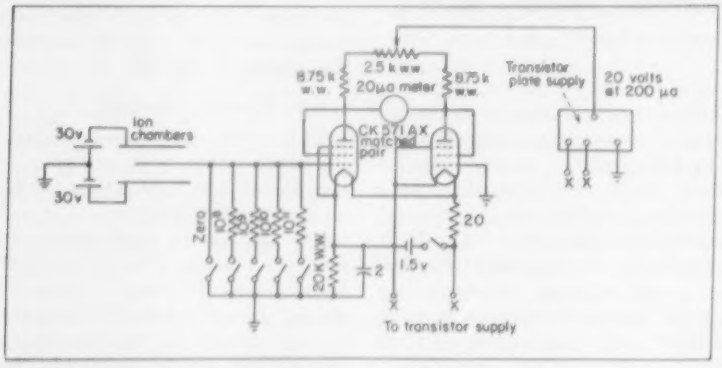


FIG. 1. Differential-type circuit used in the meter

To measure small amounts of beta-gamma contamination surrounded by relatively large gamma sources (e.g., fallout or reactor leakage areas), the masking effect of the large background must be reduced. A further advantage is to be realized by detecting the beta component of the contamination. The ionizing effect of the beta is much greater than that of the gamma. It is, also, easy to achieve directional sensitivity to beta with very light shielding. Thus, the ideal instrument for this service would utilize a detector that is sensitive only to beta and not to gamma. Such an instrument could then serve to measure the beta contamination and, indirectly, the beta-gamma contamination.

Principle of Operation

The instrument described in this article uses a beta-sensitive detector with a minimum of output from gamma.

These characteristics are obtained by means of two ion chambers—one is beta- and gamma-sensitive, and the other only gamma-sensitive—operated with opposite applied potentials. The gamma-produced outputs, being of opposite polarity, cancel. In this way the detector output is made nearly independent of gamma flux and the beta measurements can be made quickly. This is important in a region of high gamma intensity because personnel operating time may be limited by the dose rate. Furthermore, since no gamma shielding is necessary, the instrument is light and easy to handle.

Instrument Description

The ion-chamber assembly consists of three parallel plates (4 × 4 in.) insulated from each other and from the chassis by Teflon.

The lower plate, which is next to the instrument window, consists of 0.5-mil aluminum foil stretched on a narrow aluminum frame. This plate serves as the lower electrode of the beta-sensitive chamber section. The middle plate, 50-mil aluminum, is sufficient to stop betas from entering the upper section while causing minimum attenuation of gammas. The upper plate is made from aluminum sheet (thickness not critical). The spacing between plates is 0.5 in. This assembly is mounted directly beneath the electrometer section of the instrument.

The central plate is connected to the electrometer input. It serves as the upper electrode of the lower or beta chamber, and as the lower electrode of the upper or gamma-bucking chamber. The chamber dimensions and spacings were chosen to obtain a favorable ratio of beta-to-gamma sensitivity, thereby minimizing the amount of gamma effect to be balanced out.

A differential electrometer circuit is employed (Fig. 1). This circuit provides good linearity, is simple, and has minimum zero drift due to its inherent compensation for variations in filament and plate voltages. Zero adjustment is accomplished by a potentiometer in the plate circuit. Once set, the zero will remain stable for at least several hours. The circuit uses two 5886 tubes that have been aged and matched. With a 20-μa meter and the circuit constants used, a full-scale sensitivity of 0.4 volt results.

Four ranges are used, 0–20, 0–200, 0–2,000, and 0–20,000 μc and are obtained by utilizing electrometer input resistors of 10^{11}, 10^{10}, 10^{9}, and 10^{8} ohms, respectively. A zero test position is included. In this position, the input grid is shorted, allowing zero check and set while in a beta-gamma field.

Calibration

Calibration is accomplished by the use of standard beta samples (Sr^{90}-Y^{90}), which are, essentially, point sources. The sensitivity of the electrometer is varied by adjusting the value of the

Visit this Martin Exhibit at the Atomic Trade Fair

BOOTH 235

These Phones hold the story of the Martin Portable Power Plant . . .

Packaged in seven aluminum pods, which become the permanent housing for the installation, this complete power plant has been designed to be transported by air to your location, wherever it may be . . . mountains, desert, anywhere. The whole story plus this model will be in Booth No. 235, Atomic Trade Fair, Navy Pier, Chicago, September 24-28.

You are cordially invited to spend some time at the Martin exhibit. Not only will you learn about this Portable Power Plant, but also about the other Martin projects, including a complete 12,500 kw power plant for the Dominican Republic.

* * *

Messrs. H. Stueber and D. Gambert will be there to welcome you.

MARTIN

common cathode resistor until the meter reading is correct. This adjustment, once made, is final and no readjustment is necessary. Indication is linear on all ranges, and calibration of any one range is sufficient to assure calibration of all ranges.

Since the available standard samples were labeled in microcuries, the instrument indication was most easily given in microcuries. The area of the window is known, 100 cm^2. Thus, conversion to microcuries per square centimeter is made simply by dividing the indicated microcuries by 100.

Readings may be changed from microcuries to millirep by multiplying by a factor of 40. On the most sensitive range, 20 mrep is easily discernible.

Although no tests of beta-energy dependency were made, because of the lack of suitable standard samples, it is expected that some dependency exists. The calibration may, therefore, not hold exactly for isotopes other than Sr^{90}-Y^{90}.

Performance

The X100 and X1,000 scales were not sensitive to 20 r/hr of gamma radiation. The error was less than 10% on the X1 scale in a 100-mr field and on the X10 scale in 1-r field. With the gamma-bucking chamber disconnected, the deviation was about ten times as great. By covering the beta window and rezeroing, it is possible to operate easily in fields up to ten times the above figures for a particular scale.

The instrument has been in field use for more than three years. High humidity has been the most acute environmental problem. It was circumvented by sealing the instruments in transparent plastic bags; this also avoided contamination. Except for very soft betas, absorption by the plastic is negligible.

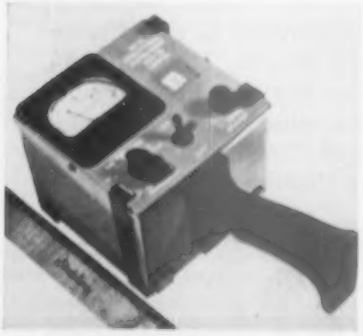
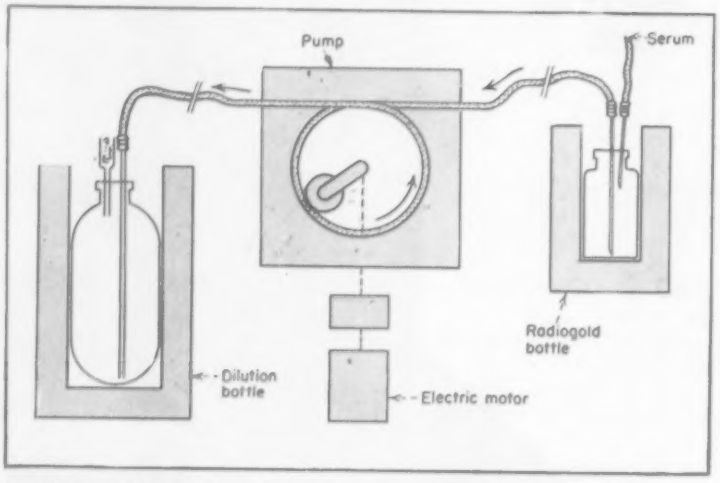


FIG. 2. Survey meter is contained in 20-gage aluminum box, 5 × 5 × 4 in. Clips hold plastic cover

Apparatus for Injecting Radioactive Colloids

By J. P. VIGNE, R. SANTELLI, and J. FONDARAI
Laboratoire des Isotopes, Centre de Lutte Contre le Cancer, Marseille, France



RADIOGOLD INJECTIONS can be made accurately with this simple apparatus

Injection of colloidal radiogold presents several problems:

1. Preparation of a suitable dilution.
2. Injection of an accurately measured volume.
3. Use of the same apparatus on several patients in series to reduce the number of manipulations.
4. Easy decontamination of the apparatus.

We tried various proposed techniques—protected syringe (*1–3*), injection of a liquid by gas pressure (*4*), and injection by hydrostatic pressure (*2*). However, we decided to use an apparatus* designed by L. Henry and P. Jouvelet generally used for blood transfusions.

This pump (see illustration) provides continual movement of liquid by pinching a turn of rubber pipe against a cylinder with a rotating wheel. The pipe is calibrated to supply 1 ml per revolution of the wheel.

This apparatus, used for filling and exhausting, contains a milliliter-graduated scale. Two small manometers measure the pressures above and below the pump to verify the passage of liquid. The apparatus we have used also has a variable-speed electric motor to turn the wheel in both directions.

In the first flow direction, the contents of the radiogold bottle are pumped into a lead-shielded Pyrex bottle through a needle inserted through the rubber stopper. Then enough physiological serum is added to obtain the desired dilution; the serum is admitted through a second needle by way of the radiogold bottle. The total volume is measured by the number of wheel revolutions.

The dilution accomplished, the tube is removed from the needle in the radiogold bottle and fitted to the ferrule of the injection trocar. By reversing the liquid flow, the desired volume is injected by counting the number of wheel revolutions.

The apparatus has the following advantages:

1. With rubber pipe of the desired length, there is only one ferrule—on the needle.
2. The pump, electrically powered, can be controlled at a distance.
3. The volume of the pipe being 1 ml for 15 cm of length, the radiation of the unshielded solution is very weak.
4. Once the operation is ended, decontamination consists of only cleaning the Pyrex bottle and the rubber.

* This apparatus is manufactured by the GAZET establishments in Noisy-le-Grand, Seine-et-Oise, France.

BIBLIOGRAPHY

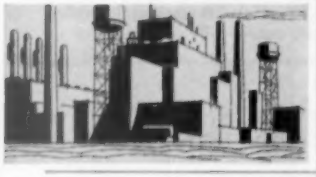
1. D. L. Tabern, Nucleonics **12**, No. 9, 57 (1954)
2. R. S. Yalow, B. B. Cohen, Nucleonics **11**, No. 12, 65 (1953)
3. M. Ter-Pogossian, A. I. Sherman, Nucleonics **10**, No. 3, 23 (1952)
4. D. L. Tabern, G. I. Gleason, R. J. Litner, Nucleonics **10**, No. 2, 63 (1952)

Kaiser Engineers' Nuclear Engineering Division has the specialized training and experience to undertake projects involving nuclear energy.

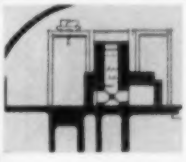
for example:

The Engineering Test Reactor facility at the National Reactor Testing Station, one of the most advanced testing reactors yet undertaken, is being designed and built by Kaiser Engineers.

For the AEC-USAF Aircraft Nuclear Propulsion Project, Lockland, Kaiser Engineers handled complete site, structure, and project planning, design of complex instrumentation, and control features.



For Special Nuclear Materials Production, large graphite-moderated reactors and appurtenant facilities were recently completed by Kaiser Engineers for the AEC at Hanford, Washington.



At the University of California's Livermore Radiation Laboratory Kaiser Engineers planned and designed special fabrication and research facilities, establishing design criteria for a proposed expansion.

write

Nuclear Engineering Division, Kaiser Engineers,
Kaiser Building, Oakland 12, California

Resolution of Two-Component Decay Data

By E. C. FREILING and L. R. BUNNEY
Chemical Technology Division
U. S. N. Radiological Defense Laboratory
San Francisco, California

The resolution of two-component decay data by the method of least squares is described here. Its principal advantage lies in its application to systems in which the shorter-lived isotope has a half-life that is inconveniently long and there is a necessity for resolving the data prior to its complete decay. Data where only a few initial counts reveal the presence of any short-lived material also can be handled.

In all cases where the half-life of each component is accurately known and the purity of the activity established, this method is the most reliable means of treating the data and establishing the limits of confidence. However because of the labor involved, it is not usually applied to well defined two-component decay curves.

Two-component decay is given by

$$A = A_1^0 e^{-\lambda_1 t} + A_2^0 e^{-\lambda_2 t} \quad (1)$$

where A is the total activity of the system at time t, A_1^0 is the activity of the first component at time $t = 0$, λ_1 is the decay constant of the first component, and A_2^0 and λ_2 are the quantities for component two. Rearranging

$$Ae^{\lambda_1 t} = A_1^0 + A_2^0 e^{(\lambda_1 - \lambda_2)t} \quad (2)$$

If λ_1 and λ_2 are so chosen that $\lambda_2 > \lambda_1$, at $t = 0$ Eq. 2 reduces to

$$A^0 = A_1^0 + A_2^0 \quad (3)$$

while at $t = \infty$ it becomes

$$Ae^{\lambda_1 t} = A_1^0 \quad (4)$$

Therefore, by plotting $Ae^{\lambda_1 t}$ vs $e^{(\lambda_1 - \lambda_2)t}$, a straight line is obtained that ranges from $e^{(\lambda_1 - \lambda_2)t} = 0$ to $e^{(\lambda_1 - \lambda_2)t} = 1$ and that has the intercepts given by Eqs. 3 and 4. These are easily solved for A_1^0 and A_2^0. The method of least squares can be applied in the usual manner to determine the line of regression and the associated parameters. See Figs. 1 and 2.

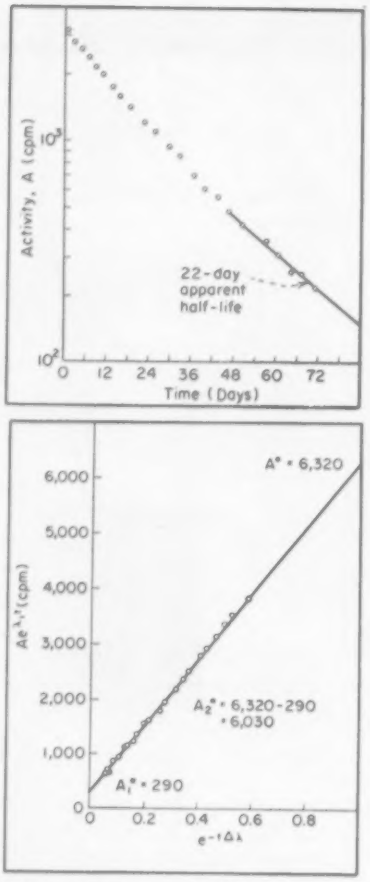
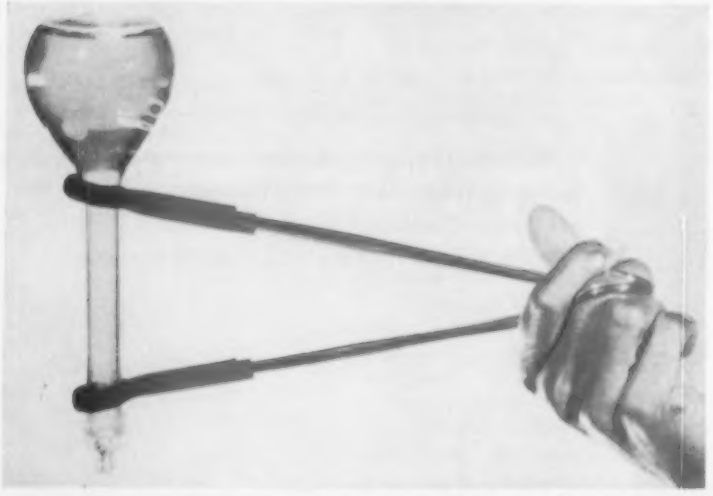


FIG. 1. Decay curve of Eu^{155} contaminated with Y^{91}. Top, conventional semilog plot; bottom, analytically resolved plot

Clamp for Handling Radioactive Liquids



Remote handling of small, thin-walled glass containers for radioactive liquids is difficult. A drop-proof clamp that applies a uniform, low pressure that has been used for some time in this laboratory with excellent results is illustrated. The clamp is made by slipping a piece of rubber tubing over the ends of a surgical clamp equipped with a rachet locking device. (Ordinary laboratory tongs without a locking device can also be used.) The rubber loop passes around the vessel and provides a slip-proof grip. An advantage is that the need to decontaminate the metal tongs in case of a spill of the radioactive liquid is minimized because the protective rubber tubing can be readily removed—A. SCHWEBEL, *National Bureau of Standards, Department of Commerce, Washington, D. C.*

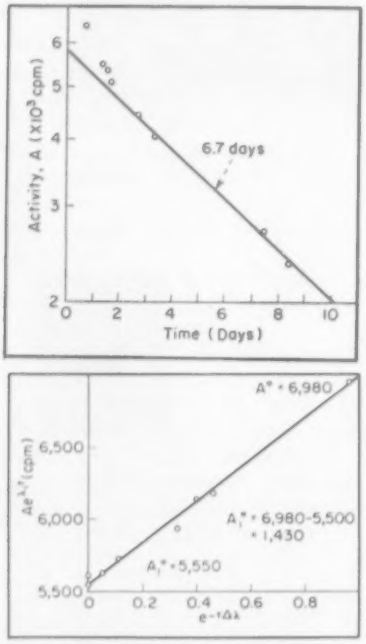


FIG. 2. Decay curve of U^{237} and U^{240} mixture. Top, conventional semilog plot; bottom, analytically resolved plot

U. S. Air Force Photo

An Air Force cargo plane delivers vital Air Force supplies to an overseas base.

AIR MATERIEL COMMAND IS GLOBAL LINK BETWEEN RESEARCH AND COMBAT UNITS

Supplying the Air Force with the right equipment, at the right place at the right time is the mission of Air Materiel Command. Its procurement, supply and maintenance operations fill the area between research and development on one side and combat units on the other. It is the largest business in the country.

Because our Air Force is operating in all quarters of the earth, AMC is a globe-circling operation with its headquarters centered at Wright-Patterson AFB near Dayton, Ohio.

The vital logistic mission for the Air Force involves billions of dollars in procurement, thousands of airplanes, and more than a million different kinds of supply items. Organizationally, AMC includes fourteen air materiel areas, or major area depots, located in the United States, Europe, North Africa, and the Pacific. Geographically, air materiel operations extend throughout the free world.

Working with weapons systems contractors in private industry, AMC procures the equipment which has been developed and tested by the Air Research and Development Command, and distributes the equipment to combat units as needed. The never ending objective of the Air Materiel Command is to maintain an instant combat readiness, logistic-wise, in this era of super speeds and super weapons to support Air Force operations at any point on the globe. The philosophy of Air Materiel Command is that such readiness must be characterized by the closest interrelations of combat and logistic elements, by speed, flexibility, mobility and economy.

This is one of a series of ads on the technical activities of the Department of Defense.

FORD INSTRUMENT COMPANY
DIVISION OF SPERRY RAND CORPORATION
31-10 Thomson Avenue, Long Island City 1, New York
Beverly Hills, Cal. • Dayton, Ohio

Highly skilled technicians at Ford Instrument Company assembling complex aircraft instruments for the U. S. Air Force.

ENGINEERS
of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.

ONLY
Koncentrik
TUBE FITTINGS
(in Stainless
Nickel and Monel)
PREVENT LEAKS
WITH THIS PATENTED
SELF-CENTERING SEAT

1. Koncentrik's exclusive, double-sealing, self-centering seat is Teflon reinforced to give you DOUBLE protection against costly, dangerous line losses. As the fitting is tightened, the "contained" Teflon rings compress into all surface irregularities, providing a leak-proof seal that is vacuum tight.

2. Heavy-duty built, Koncentrik fittings are machined from solid bar stock and forgings . . . are pressure-tight beyond burst strength of tubing.

3. Easy to install with standard flaring tools.

4. Parts are interchangeable to insure maximum economy in stocking and use.

5. The Koncentrik selection is complete . . . over 2,000 fittings for tube sizes through 2".

6. Prompt shipment through leading Stainless disbributors from coast to coast.

The full Koncentrik line of flared-tube fittings, solder and pipe couplings, and lap-joint stub ends, is covered in our new easy-reference catalog. Included also are technical data and performance figures. WRITE FOR YOUR COPY TODAY.

THE SPECIAL SCREW
PRODUCTS CO.
Bedford, Ohio

Instruments for Monitoring Tritium in the Atmosphere

By B. C. EUTSLER, G. L. EVANS,* R. D. HIEBERT, R. N. MITCHELL, M. C. ROBBINS,† and R. J. WATTS
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

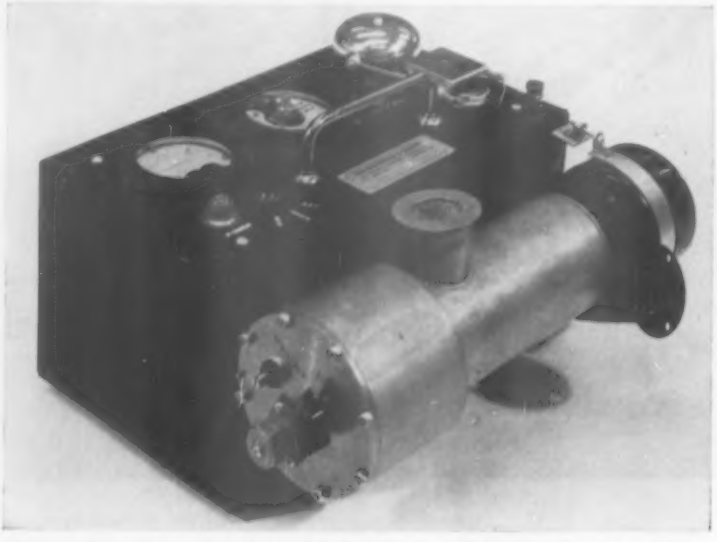


FIG. 1. Air is drawn through chamber by blower. Moistureproof housing on end of chamber protects electrometer tube and high resistances in grid. Sensitrol relay in series with microammeter ring alarm bell at full scale

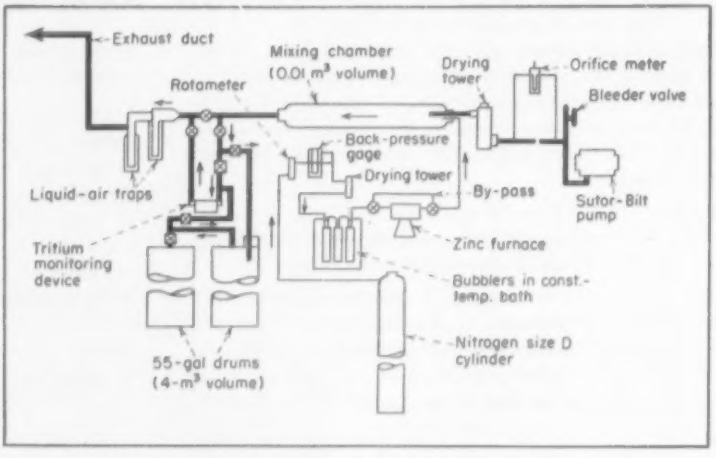


FIG. 2. The stream of air or nitrogen was passed through rotameter at constant back-pressure reading and dried in calcium chloride drying tower. Dried air was saturated with water containing tritium oxide by passing it through fritted glass bubbles at constant temperature. Saturated air next flowed through by-pass or through zinc furnace when gaseous tritium was desired, and into mixing chamber. Diluting air volume was controlled by bleeder valve and measured by orifice meter. When dry air was used, known volume of diluting air was dried in calcium chloride drying tower. When high humidities were desired, drying tower could be converted by filling it with wet glass wool. Diluting air then passed into mixing chamber where it was mixed with air containing tritium

* G. L. Evans, member of the technical staff of Hughes Aircraft Co.

† M. C. Robbins, member of the technical staff of Boeing Airplane Co.

The problem of monitoring for tritium in the atmosphere is intensified with the increasing use of H^3.

When it is considered that the toxicity of the substance may be roughly compared with that of HCN (in the sense that a full breath is lethal), it can be appreciated that care must be exercised with even moderate amounts.

It is desirable, therefore, to have a relatively inexpensive simple instrument to detect the escape of tritium.

Quick response was desired, and this requirement, coupled with that of simplicity, suggested that an ion-chamber instrument would perhaps be the best approach. However, the low average energy of the tritium betas indicated that if thin windows were to be used they must be much less than 1 mg/cm^2. This did not appear to be attractive if many windows were desired.

It was then decided that a simple type of conductivity chamber would be investigated. Unfortunately, this method would not produce an unambiguous response to tritium, but it did have the prospect of simplicity and sufficient sensitivity.

Three variations were built, a d-c model, an a-c model, and a multistation logarithmic type. Figure 1 shows the a-c model generally described as a "sniffer." A type 5800 electrometer tube is used to measure full-scale ionization currents from 10^{-12} to 10^{-9} ampere in four linear ranges. Maximum current amplification is 2×10^7 and the output is fed to a sensitrol relay, which sets off an alarm when full-scale reading is reached. The circuits are well known to the art; the d-c circuit is based on that described in Elmore and Sands (*1*). The logarithmic circuit employs a diode in the grid of the electrometer tube as a nonlinear element.

Performance

Although these instruments were designed as alarm devices, it was important to investigate their behavior in terms of tritium concentration. Fig-

What is a Tritium Sniffer?

Ions formed in the air by tritium betas are drawn through a chamber where they are collected.

This instrument differs from the usual ion chamber in that the ions formed by the disintegration of tritium in the chamber are not a dominant contributor to the current.

Advances in Applied Radiation

DEVELOPMENTS in APPLIED RADIATION ENERGY, its APPLICATIONS and the APPARATUS USED TO PRODUCE IT

For practical and profitable application of radiation energy.

Dollars-and-Cents Facts about High-voltage Electron-beam Processing

what it is, how it is being used, what it is accomplishing, and how much it costs . . . are given in our new handbook on radiation processing. To help you evaluate this modern processing method with respect to *your* product, this handbook discusses

- types of radiation and their sources
- characteristics of several forms of radiation with comments on their practicality for processing
- electron-beam radiation dosage
- electron-beam penetration
- efficiency of electron-beam utilization
- efficiency of area irradiation
- thickness efficiency of absorption
- electron-beam power output and production capacity
- accelerator principles, installation, and use
- economics of radiation processing today

See our exhibit at the Trade Fair of the Atomic Industry Chicago • September 24-28 • Booths 111-112

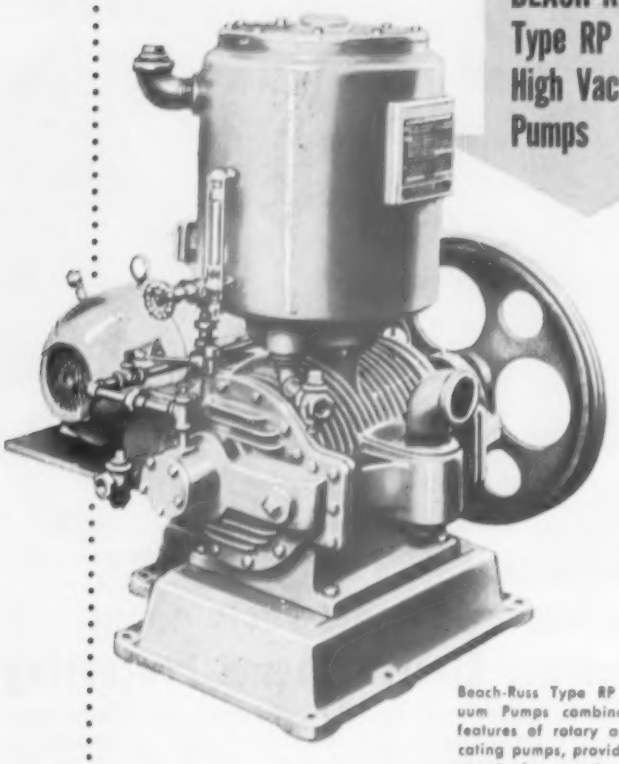
Write today for your copy of this useful handbook — free when requested on business letterhead.

HIGH VOLTAGE ENGINEERING CORPORATION

7 UNIVERSITY ROAD CAMBRIDGE 38, MASSACHUSETTS

GET DOWN TO MICRON-RANGE VACUUM MUCH Faster!

with BEACH-RUSS Type RP High Vacuum Pumps



Beach-Russ Type RP High Vacuum Pumps combine the best features of rotary and reciprocating pumps, providing greater speed of evacuation, consistent high vacuum, low power consumption and longer service life.

You can take your system down to working vacuum faster than with any other type of pump. They not only pump down faster, but operate at much higher mechanical efficiency and show the lowest over-all operating and maintenance costs in the field as a result of their precise and sturdy construction. Their exceptionally slow speed makes them virtually noiseless and vibration-free.

Write for the Beach-Russ RP Catalog for full details on these pumps. They are available in capacities from 20 to 1700 cfm for vacuum up to 10 microns or better and can also be supplied in compound types.

BEACH-RUSS COMPANY
50 Church Street • New York 7, N. Y.
Address Department 66

ure 2 is a schematic of the calibration equipment. This was so arranged that the mixed air could be held an extra length of time in a by-pass consisting of two 55-gal drums.

One of the problems encountered was the build-up of static charge on the glass of the mixing chamber. This was overcome with a covering of grounded aluminum foil.

The "hold-time" from the generation of tritium gas to the passage of ions through the instrument is of utmost importance because the mean life of both small and large ions in the atmosphere is 5–20 min (*2*). Figure 3 illustrates this effect.

Figure 4 illustrates the effect of change in air flow rate. In practice the collection of lint and dirt on the ion-chamber screen is the principal cause of diminished air flow.

All calibrations were based upon an average relative humidity of 30%. The same calibrations at 75% relative humidity gave no significant difference in reading. Cruder experiments at even higher humidity also gave the same result. This could be attributed to the placing of the Teflon insulators out of the direct air stream.

In further experiments a 90-volt ion trap was inserted ahead of the chamber to take out incoming ions. Thus only ions formed by tritium in the chamber were measured. The ion trap collected greater than 90% of the ionization. As a consequence the sensitivity decreased by more than a factor of 10.

Calibrations were also performed for tritium as 100% HTO and as a gaseous mixture of 60% HT and 40% HTO. The response of the instrument was the same in both cases.

Conclusions

On the most sensitive scale the average full-scale reading for a number of instruments corresponded to 80 microcuries of tritium per cubic meter of air. This can be contrasted with the observation that for routine testing a lighted match will ring the bell on scale 3.

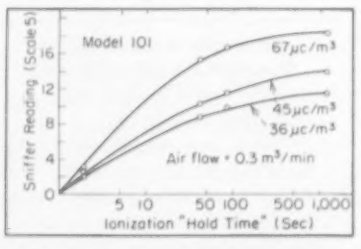


FIG. 3. Effect of "hold-time" on sensitivity

It should be emphasized that these instruments are primarily warning devices and that the operator must be aware of the limitations. The recommended maximum permissible concentration (*3*) is 2×10^{-5} μc per milliliter (20 μc/m³) of air for a 168-hr week. For a 40-hr week, this might be increased by a factor of four so that full scale on the most sensitive scale is in the neighborhood of tolerance for a 40-hr week. However, we do not recommend using this instrument for this purpose since the environment is not under sufficient control.

Inasmuch as these instruments will operate on any source of ionization such as Bunsen burners, their use requires some control over the environment. Usually tritium systems are enclosed in glass or plastic hoods, and these instruments are small enough to go into such a container.

Although a knowledge of the "equilibrium time" is important, in actual use of the instruments as warning devices, it is not essential. That is, glass tritium systems have been observed to crack and the instrument rings immediately. Subsequent experiments showed that this was true even when the instrument was 30 ft from the source.

This behavior may be attributed to two facts. First, tritium gas diffuses very rapidly through the atmosphere, and second, in such cases more than tolerance amounts were released. Thus, although the equilibrium conditions were not established, there was still a sufficient number of ions formed.

* * *

This work was done under the auspices of the U. S. Atomic Energy Commission. A more detailed account of this work may be found in LA-1909.

BIBLIOGRAPHY

1. W. C. Elmore, M. Sands, "Electronic Techniques," 1st ed., p. 186 (McGraw-Hill Book Company, Inc., New York, 1949)
2. T. F. Malone, ed., "Compendium of Meteorology," p. 120 (Waverly Press, Baltimore, 1951)
3. National Bureau of Standards Handbook 52, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water" (U. S. Department of Commerce, Washington, D. C., 1953)

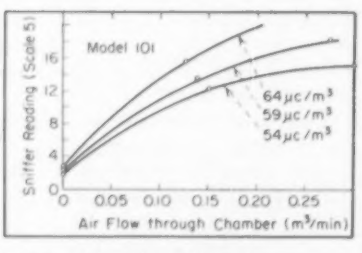
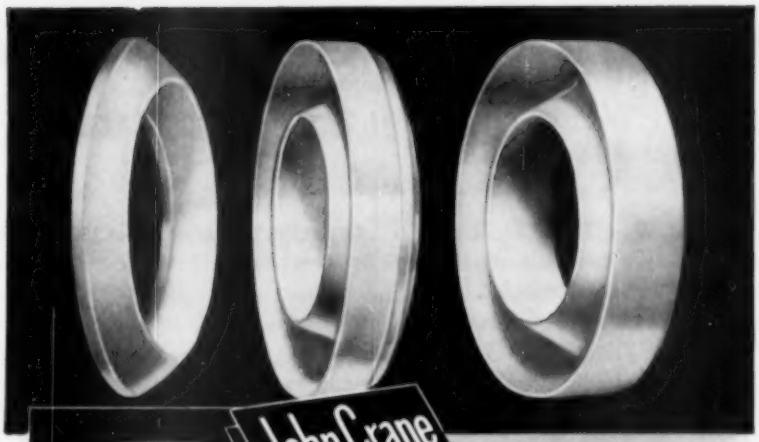


FIG. 4. Effect of air-flow rate



John Crane

CHEMLON *

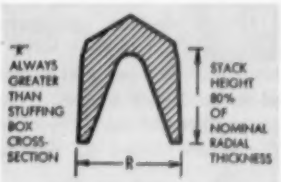
C-V RINGS

ARE INDUSTRY'S MOST UNIVERSAL PACKING . . .

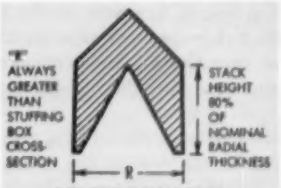
Countless successful applications of C-V Rings under the most severe service conditions have made this the closest approach to a universal packing.

It will effectively handle all industrial acids, alkalis, solvents, organic and hydraulic fluids . . . temperatures from −120°F. to +500°F. . . . is equally suited to valves, pumps, mixers, hydraulic cylinders and like equipment.

"John Crane" C-V Rings have extremely low coefficient of friction. "Breakout" friction is only slightly higher than running friction.



C-VU RING CONSTRUCTION



C-VH RING CONSTRUCTION

TWO STYLES ARE AVAILABLE:

C-VU RINGS *for low pressure service* —such as control and regulator valves handling gases and fluids, where it is necessary to have a very sensitive and resilient type packing.

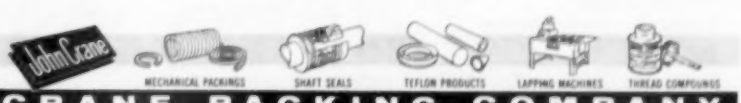
C-VH RINGS *for high pressure service* —for use in pumps, hydraulic cylinders and like services at pressures ranging to 500 psi. and over. These rings are constructed with a heavy wall heel to withstand pressure requirements. They are designed to provide voids between rings, so that as the Teflon expands due to heat, this take-up room minimizes any excess friction in the stuffing box.

"John Crane" C-V Rings are available in full line of standard sizes and male and female adaptors. Sizes can be molded to stuffing box specifications.

Request Bulletin T-110.

*"John Crane" C-V Rings are made from Chemlon—*the best in DuPont Teflon.*

Crane Packing Co., 6449 Oakton St., Morton Grove, Ill. (Chicago Suburb). *In Canada: Crane Packing Co., Ltd., Hamilton, Ont.*



CRANE PACKING COMPANY

WKNL IN THE NEWS

NUCLEAR AIRCRAFT

Walter Kidde Nuclear Laboratories has been selected by the Glenn L. Martin Company to begin engineering for extensive test facilities related to the Navy Nuclear Powered Aircraft Program.

★ ★ ★

NUCLEAR POWER PLANT

Corps of Engineers, Research and Development Laboratories, Fort Belvoir, Virginia, has selected WKNL to design a one-cycle emergency nuclear power plant. Design is expected to be completed in approximately seven months.

★ ★ ★

NUCLEAR-MINDED

Among WKNL's clients are a number of the nation's leading corporations, including Curtiss-Wright Corporation, Convair Division of General Dynamics Corporation, Continental Oil Company, Westinghouse Electric Corporation, Baldwin-Lima-Hamilton Corporation and others. A growing trend is that more and more companies are making their own privately-financed investigations into various applications of nuclear technology to their own products and processes.

Consultants to industry on applications of nuclear technology

ENGINEERING WKNL SCIENCE

WALTER KIDDE NUCLEAR LABORATORIES, INC.

975 Stewart Ave., Garden City, N. Y.
Telephone Pioneer 1-4350

Electron Accelerator Used for Producing Neutrons

By ALFRED J. MOSES and JEROME SALDICK

General Electric Company, Aircraft Nuclear Propulsion Department, Cincinnati, Ohio

We have used a 250-μa, 2-Mev accelerator to provide a 10^7 cm^{-2} sec^{-1} thermal-neutron flux over a useful volume of several cubic centimeters.

This flux is considerably lower than the flux in nuclear reactors, but considerably higher than that obtainable from portable Ra-Be, Po-Be, or Sb-Be sources. It is comparable to that obtainable from "low-cost" positive-ion accelerators, which use the $D(d,n)T$ reaction (*1*, *2*). Such a flux is sufficient to produce useful quantities of radioisotopes that are too short-lived to be transported appreciable distances. It also permits extension of activation analysis to microgram amounts of impurities in favorable cases.

Apparatus and Procedure

A High Voltage Engineering Corp. Van de Graaff electron accelerator rated at 250-μa and 2-Mev, with a ¼-in.-thick, water-cooled gold target, was used as an X-ray source. Neutrons were produced by the $Be^9(\gamma,n)Be^8$ reaction, and moderated by paraffin and beryllium.

The target assembly is shown in Fig. 1. In part the dimensions were set by the size of available blocks of beryllium, but preliminary experiments indicated that the arrangement gave nearly the optimum thermal-neutron flux.

The samples were placed in a slight depression in the top of the smaller paraffin block of the sample holder. It was advisable to keep the samples centered on the block, because the flux was 30% lower, 1 in. off center. All irradiations were performed using a 250-μa electron beam.

Indium-containing foils were irradiated to measure the neutron flux. Cadmium covers were used to determine the thermal and epithermal flux components. Corrections were made for self-absorption and self-scattering by rolling out foils to various thicknesses, irradiating them, and extrapolating counting rates to zero thickness. Counting was done with a windowless proportional flow counter using a heavy platinum backing for the foils to make the counting rate independent of the energy of the emitted beta particle (*3*).

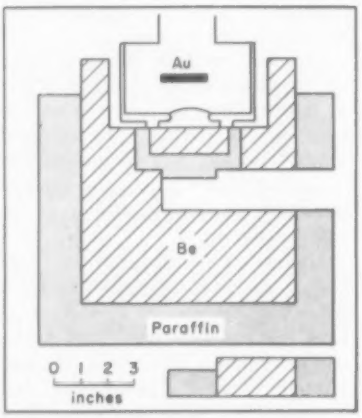


FIG. 1. Cross section of beryllium target assembly and sample holder

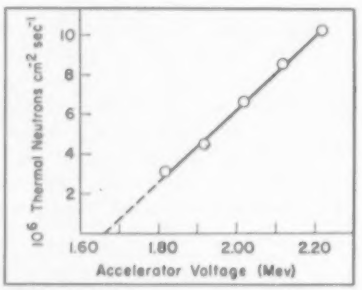


FIG. 2. Thermal flux as function of accelerator voltage

Results

The thermal-neutron fluxes obtained are shown in Fig. 2. Irradiations using a 2.1-Mev, 250-μa beam gave a steady flux of 8.5×10^6 thermal neutrons cm^{-2} sec^{-1}, readily reproducible within 5%.*

Calculations were made as described by Senftle (*4*). The thermal neutron cross-section of In^{115} for the production of 54-min In^{116} was taken as 1.45 ×

* Our accelerator was operated continuously at 2.1 Mev, and for 5-min periods at 2.2 Mev.

10^{-22} cm^2 (*5*). The isotopic abundance of In^{115} is 95.77% (*6*). Corrections were made for the attenuation of the epithermal neutron flux by cadmium (*7*, *8*). Thermal neutron leakage through the cadmium (*8*) and the depression of thermal-neutron flux by the indium and aluminum in the bare foils (*7*) were considered negligible.

The ratios of the total activation to activations due to epicadmium neutrons were all close to 2.5.

Applications

Neutron activation analysis as an analytical tool has been somewhat limited because radium-beryllium or similar sources do not yield sufficient neutron fluxes for the detecting and determining trace amounts. Nuclear reactors with high neutron fluxes are not always readily accessible. With a thermal neutron flux of 10^7 cm^{-2} sec^{-1}, microgram and often submicrogram quantities of many elements may be determined. With a 3-Mev accelerator, rough extrapolation (*9*) indicates that a 250-μa current will produce 10^8 cm^{-2} sec^{-1} thermal-neutron fluxes.

Several good tabulations of sensitivities are available (*1*, *10*, *11*). Since the sensitivities are inversely proportional to the neutron flux used, the figures may be applied to any neutron source. For some elements, quantities undetectable by all other methods can be determined by activation analysis using the flux produced by the above technique (*2*).

Appreciable quantities of isotopes of short and medium half-lives for both tracer use and fundamental investigations may be produced with the flux available by this technique. The Szilard-Chalmers effect (*12*) can often be used to obtain them nearly carrier-free. Examples of such an application are the production of 4.4-hr Br^{80} and 2.6-hr Mn^{56}.

BIBLIOGRAPHY

1. W. W. Meinke, R. E. Anderson, *Anal. Chem.* **25**, 778 (1953)
2. W. W. Meinke, *Science* **121**, 3137 (1955)
3. D. Christian, W. W. Dunning, D. S. Martin, Jr., NUCLEONICS **10**, No. 5, 41 (1952)
4. F. E. Senftle, W. Z. Leavitt, NUCLEONICS **6**, No. 5, 54 (1950)
5. L. Seren, H. N. Friedlander, S. Turkel, *Phys. Rev.* **72**, 888 (1947)
6. J. R. White, A. E. Cameron, *Phys. Rev.* **74**, 991 (1948)
7. C. W. Tittle, NUCLEONICS **8**, No. 6, 5 (1951); **9**, No. 1, 60 (1951)
8. D. H. Martin, NUCLEONICS **13**, No. 3, 52 (1955)
9. M. L. Wiedenbeck, *Phys. Rev.* **69**, 235 (1946)
10. A. E. Smales, *Atomics* **4**, 55 (1953)
11. E. A. Burrill, A. J. Gale, "Activation Analysis with Van de Graaff Neutron Sources" (High Voltage Engineering Corp., Cambridge, 1954)
12. R. R. Williams, *J. Phys. & Colloid Chem.* **52**, 603 (1948)

If you are interested in.....

INDUSTRIAL APPLICATIONS OF RADIOISOTOPES

Tracer Research involving industrial organic compounds—oil and gasoline, solvents, pharmaceuticals, plastics.

Ground Water Studies—large scale water distribution problems, such as pollution and waste disposal.

Large Scale Tagging of plant operation with safety and economy of radioactive materials.

You should consider...

LOW LEVEL COUNTING OF SOFT BETA EMITTERS

Every single organic compound can be uniquely identified with the radioactive isotopes of hydrogen and carbon. These isotopes—Tritium and Carbon-14—are readily available and simple to use. They emit very soft beta radiation which cannot penetrate even a thin glass container.

Sulphur-35 and Calcium-45 are other common soft beta emitters now being successfully used in wide industrial applications.

See what can be done with the...

PACKARD TRI-CARB LIQUID SCINTILLATION SPECTROMETER

The Tri-Carb Spectrometer is simple to use. Most samples are easily prepared and hundreds per day can be readily handled. In addition to samples that are soluble in the scintillation solvent, it is also possible to count many entirely different classes of materials. Aqueous samples, completely insoluble solids, CO_2, H_2S, SO_2, and heavy metals can all be counted efficiently by recently developed sample preparation techniques.

The Tri-Carb Spectrometer makes possible the labeling of end products at or below the level of natural radiocarbon. This is the level that exists in the atmosphere and consequently in all plants and animals living today. As a matter of fact, the liquid scintillation method permits archeological dating by measuring the level of radiocarbon remaining in preserved organic materials that were living over 40,000 years ago. For industrial applications the use of equipment with this sensitivity should remove all objections to radioactive labeling of consumer products.

Request Tri-Carb Bulletin for general data. For specific information on your requirements, give us details of your application.

Packard Instrument Company

DEPT. B • P.O. BOX 428 • LA GRANGE, ILLINOIS

WHAT ARE YOUR

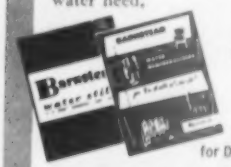
HOH

PROBLEMS

- ☐ Suspended Solids
- ☐ Cold Crud Filtration
- ☐ Low Ionizable Solids
- ☐ Colloidal Matter
- ☐ Bacteria Removal
- ☐ Waste Disposal
- ☐ Oxygen Removal
- ☐ Parts Rinsing
- ☐ Nitrogen Removal
- ☐ Ammonia Addition
- ☐ CO_2 Removal
- ☐ Trace Mineral Recovery
- ☐ Test Loops
- ☐ Air-borne Impurities
- ☐ Reactor Moderator
- ☐ 10,000,000 Ohm Water

Your Water Purification Problems Will Receive an Impartial Answer from Barnstead

Whatever your pure water problem . . . whether it requires distilled or demineralized water — or both — you can be assured of a technically sound, technically correct solution from Barnstead. For *ONLY* Barnstead makes both . . . a complete line of Stills and Demineralizers for *EVERY* pure water need.



WRITE FOR INFORMATIVE CATALOGS

Catalog "G" For Stills . . . Catalog 127 for Demineralizers

Pure Water Specialists Since 1878

Barnstead
STILL & DEMINERALIZER CO.

34 Lanesville Terrace
Boston 31, Mass.

Scintillation Counter for Beta-Ray Dosimetry

By PAUL N. GOODWIN
Department of Radiology
U. S. Public Health Service Hospital
Baltimore, Maryland

Beta-ray dosimetry in biology and medicine involves the determination of the energy absorbed per unit volume by tissue or tissue-equivalent material at various distances from beta-emitting isotopes.

For such dosimetry we employ a scintillation counter. It uses plastic scintillation material to determine the relative energy absorption at various depths from plane sources and the relative variations of energy absorption around small plane sources of several beta emitters.

Previous measurements of beta-ray depth doses have been made with extrapolation chambers and with scintillation counters such as the one described by Ittner and Ter-Pogossian (*1*). The counter described here is simpler to construct, uses only tissue-equivalent substances for the detector and surrounding materials, and is adaptable to a wide variety of beta-ray measuring problems.

The counter and counter housing are shown in Fig. 1. The ½ in. (or more) of polystyrene or Lucite between the tube and the sources is sufficient to prevent the beta particles from reaching the cathode. Polystyrene may be used above the tube; its density of 1.05 and effective atomic number of 5.74 make it essentially tissue-equivalent, but it exhibits considerable natural fluorescense under beta bombardment. This effect may be subtracted out, but it is preferable to use Lucite, which has much less fluorescence. Its density of 1.14 is slightly higher than polystyrene, but since the Lucite only affects back-scattered beta particles, the effect on the present measurements is entirely negligible.

All scintillating detectors used were cut from pieces of "Scintilon" plastic scintillator manufactured by National Radiac Co. Its physical properties are similar to polystyrene, its density is 1.05, and the plastic may be considered sufficiently tissue equivalent.

Figure 2 shows in detail the detector and surrounding materials. The detec-

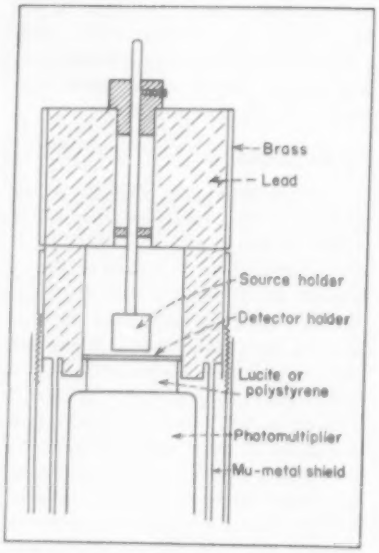


FIG. 1. The scintillation counter

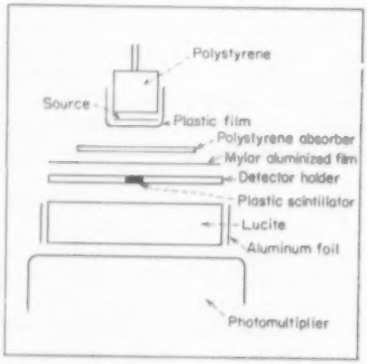


FIG. 2. Exploded view of source and detector

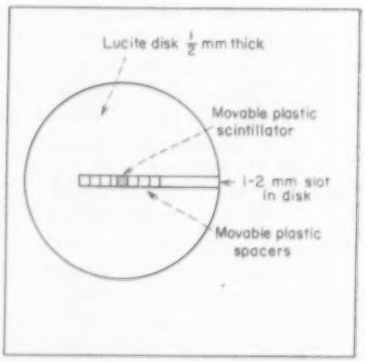
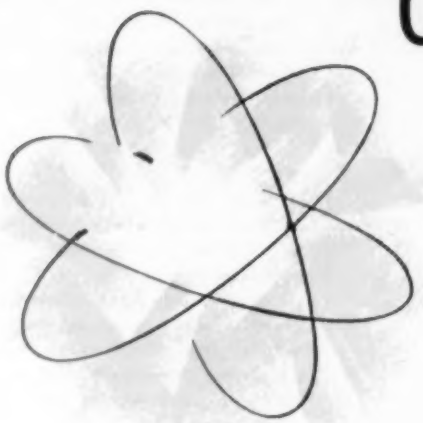


FIG. 3. Top view of detector holder

Announcing...

Fairchild reactor control



equipments and complete packaged systems featuring transistors and magnetic amplifiers

Our Nuclear Instrumentation Department has developed circuitry using transistors and magnetic amplifiers exclusively to increase life and insure maximum reliability.

The following systems and their component equipments are now available:

- Reactor Power Level Monitoring and Control Systems and Equipments
- Control Rod Drive Mechanisms and associated Power Supplies
- Radiation Monitoring Systems, Equipments and Accessories
- Primary Plant Instrumentation Systems Equipments and associated Amplifiers

The design and development of these nuclear instrumentation systems are the logical outgrowth of thirty-five years of Fairchild leadership in *precision* electronics and mechanics in both military and commercial fields. The experience, the facilities, the personnel built up over this period are directed by an experienced staff of nuclear scientists and engineers.

Fairchild will be pleased to supply detailed technical information on these systems and equipments. The staff is also available for exploratory discussions of individual research and development programs. Write or contact Dept. 150-1N, Robbins Lane, Syosset, L.I., N.Y

Nuclear Instrumentation Department
Reconnaissance Systems Division

FAIRCHILD
CAMERA AND INSTRUMENT
CORPORATION

EXCEPTIONAL CAREER OPPORTUNITIES OPEN TO ENGINEERS, TECHNICIANS, DRAFTSMEN. WRITE TO PERSONNEL DIRECTOR

LITHIUM METAL AND ALLOYS
LITHIUM HYDRIDE
LITHIUM HYDROXIDE
LITHIUM CARBONATE
LITHIUM CHLORIDE—BRINE—etc.

LITHIUM
MAYWOOD

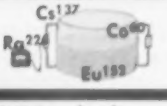
Pioneers in Lithium since 1901

MAYWOOD CHEMICAL WORKS
MAYWOOD, NEW JERSEY
ESTABLISHED 1895

RADIOISOTOPES
for RESEARCH and PROCESS CONTROL

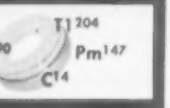
BETA SOURCES . . . for inclusion in thickness and density gauges for stationary or moving stock.

GAMMA SOURCES . . . for utilization in density and liquid level gauges, instrument calibration and irradiation studies.



ALPHA; BETA SOURCES . . . ionization for stabilization of electrical discharge in gaseous medium; analysis of gaseous mixtures, static elimination.

BETA SOURCES . . . featuring excitation of phosphors for illumination, safety marking and photometry.



NEUTRON SOURCES . . . activation analysis, oil well logging

RADIUM

For further information write Dept. N9
UNITED STATES RADIUM CORP.
Hanover Ave., Morristown, N. J.

Regional Offices: 5420 Vineland Ave., N. Hollywood, Calif.; 4624 W. Washington Blvd., Chicago, Ill. Affiliates: In Canada – Radelin-Kirk Ltd., 1168 Bay St., Toronto, Ont.; In Europe – United States Radium Corp.-Europe, 36 Avenue Krieg, Geneva, Switzerland.

tor holders were Lucite disks (Fig. 3). By using Lucite or polystyrene spacers, the detector can be placed in various positions along the slot. A film of double-coated "Mylar" was placed above the detector holder. This gave the same optical geometry for the detector regardless of the amount of polystyrene absorber between the source and detector. The Mylar was an aluminized plastic film having a thickness of less than 0.01 mm and a density of 1 mg/cm^2.

Polystyrene absorbers in the form of 1-in. disks of various thicknesses were placed between the Mylar film and the beta source. Disks ½–3 mm thick were cut by slicing up a polystyrene rod in a lathe. Disks less than ½ mm were made by melting polystyrene as described by Lagiss (*2*).

Small plane sources of I^{131}, RaD-E, and P^{32} were prepared by saturating circular disks of filter paper with aqueous solutions of the isotopes, and allowing the paper to dry. Uniform distributions were obtained by placing the disks on top of a glass tube of equal diameter, and then trimming the edges after drying. The sources thus prepared were placed on the end of a polystyrene rod and covered with a plastic film 0.02 mm thick.

A negative high voltage was used on the phototube, and the anode connected through a galvanometer to ground. The galvanometer was a Rubicon "Spotlight" galvanometer having a scale sensitivity of 0.0021 μa/mm, with a shunt to reduce the sensitivity for the more intense readings.

Measurements were made of the relative energy absorption directly below the center of small plane beta sources, using a detector 2 × 2 mm by ½ mm thick. Readings were taken for Sr^{90}, RaD-E, and P^{32}, and plotted as per cent of the maximum intensity. The resulting absorption curves are shown in Fig. 4.

Measurements of the distribution of energy absorption around small plane beta sources were made by placing the detector in a slotted disk (Fig. 3) and taking readings with the detector in various positions along the slot, and various thicknesses of polystyrene above the detector. An example of the isodose curves thus obtained is shown in Fig. 5, made with a "Tracerlab" Sr^{90}-Y^{90} source having an active diameter of 6.6 mm.

The decrease in intensity along the axis of the Sr^{90} disk source followed an equation of the form $(1/r^2)e^{-\mu r}$ at dis-

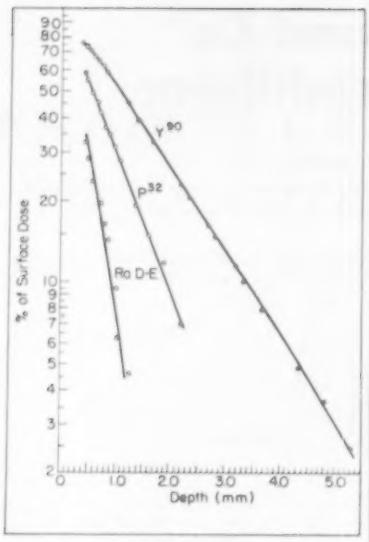


FIG. 4. Central-axis depth doses as obtained with detector 2 × 2 × ½ mm

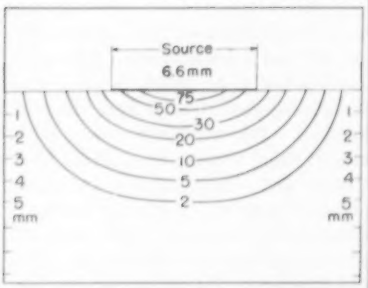


FIG. 5. Isodose curves for Sr^{90}-Y^{90} applicator obtained with detector shown in Fig. 3

tances greater than about 2 mm. At closer distances, the intensity dropped considerably below the values calculated from such an equation. This phenomenon is similar to that found by others (*3*) who have made beta-absorption measurements close to point sources in air. However, the apparatus described here permits a direct attack on the problem of beta absorption close to a source in an absorbing medium. Further measurements are now being made, and attempts are being made to put the results on a sound theoretical basis.

* * *

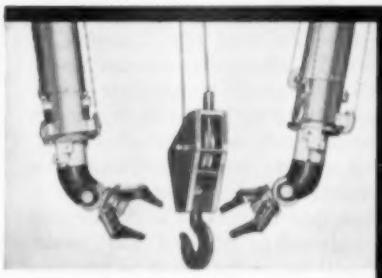
The author wishes to thank Professor George E. Owen of the Physics Department, Johns Hopkins University, for his advice and continued interest in this project.

BIBLIOGRAPHY

1. W. B. Ittner III, M. Ter-Pogossian. Scintillation probe for determining relative beta-ray intensities. NUCLEONICS **12**, No. 5, 56 (1954)
2. C. Lagiss. Thin plastic scintillators. NUCLEONICS **14**, No. 3, 66 (1956)
3. R. Loevinger. *Radiology* **66**, No. 1, 55 (1956)

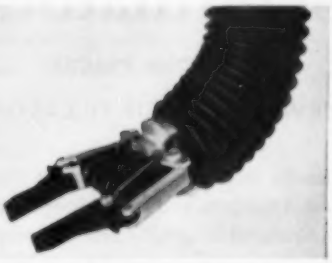
CRL manipulators
plus
CRL accessories
equals
versatility

One of the important characteristics leading to the choice of Master-Slave Manipulators for most hot cells currently being constructed is versatility. The wise buyer who obtains manipulators from Central Research Laboratories will be happy to know that a wide variety of accessories are available from CRL to augment this versatility.



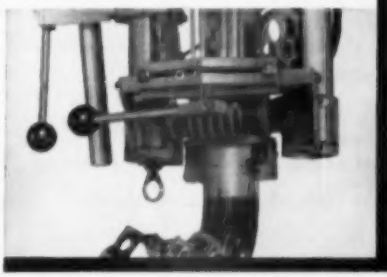
Cranes and Hoists. Lifting and moving of heavy loads in hot-cell areas may be accomplished by remote-control cranes and hoists specially designed and manufactured by CRL for use with Master-Slave Manipulators.

Flexible Booting protects slave end of manipulator from dust, contamination, and corrosion. Restricted gas-flow seal possible. Does not interfere with any of the manipulator's natural movements.



Special Purpose Tongs. For repetitive or highly specialized operations, specially-designed, remotely-interchangeable tongs can be supplied to increase speed and ease of operation.

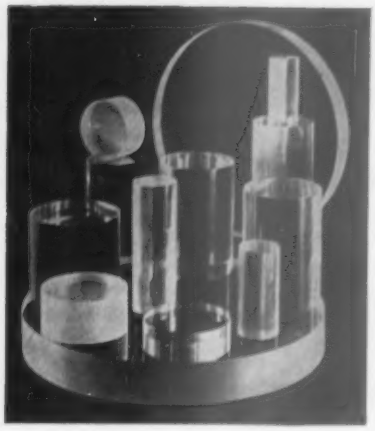
Load Hook available for CRL Model 8 may be remotely attached or detached and permits a vertical lift of 60 pounds.



Motion Locks enable one to position rigidly in space any object which the manipulator can handle. Locking grip is standard equipment on all models. Locks for all other rotation, translation, and elevation motions are available as extra accessories.

For more information on special applications of CRL Master-Slave Manipulators, phone or write today to

Central Research **laboratories, inc.**
Dept. 103, Red Wing, Minnesota



Plastic Scintillators

NEW LOW PRICES!

NEW X-RAY SCINTILLATOR!

Rapidly increasing production of Nash and Thompson's Plastic Scintillators has resulted in greatly reduced prices. Scintillators are now available at figures competitive with any other producer in the world, e.g. :—

6″ diameter x 1″ thick—ONLY $46.20
2″ diameter x 1″ thick—ONLY $ 7.00

The new X-ray phosphor, primarily for medical use, is "air equivalent" and has a linear response within the range of 500 KeV to 25 KeV.

Other Scintillators available include crystals of Sodium Iodide, Potassium Iodide, Anthracene, and Stilbene.

Nucleonic equipments include Portable Dust Sampler, Quartz Fibre Measuring Device and 3-Channel direct Microamp Recorder.

WRITE TODAY FOR FULL DETAILS

Nash and Thompson

LIMITED

Oakcroft Road, Chessington, Surrey, England

Detection of S^{35} and Ca^{45} with a Plastic Scintillator

By MARVIN L. MITCHELL and LOUIS A. SARKES

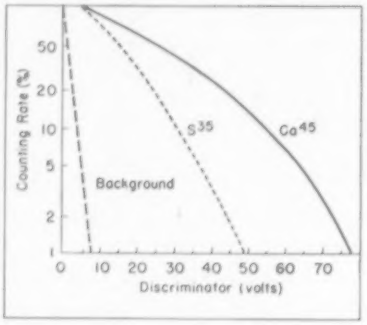
Radioisotope Units of Lemuel Shattuck Hospital, Massachusetts Dept. of Public Health, and Boston Veterans Administration Hospital, Boston, Massachusetts

In the past extremely thin plastic scintillators have been used to detect heavy radioactive particles such as protons and alphas (*1*) while thicker plastic phosphors have proved to be efficient for detecting gamma and high-energy beta rays (*2*). Therefore, it seemed worthwhile to examine plastic scintillators of an intermediate size for their ability to detect beta rays of low energies, such as those of S^{35} and Ca^{45}.

A round plastic scintillator* was selected, 1 in. in diameter and $\frac{1}{8}$ in. thick, which appeared to be adequate for detecting S^{35} and Ca^{45} betas. This thickness proved to be relatively insensitive to gamma rays and registered a background of such low magnitude that heavy lead shielding was unnecessary.

A light-tight aluminum housing was constructed to contain the radioactive source and the photomultiplier tube. The scintillator, optically coupled† to the phototube, was inserted far down into the mouth of an upright aluminum cylinder and held firmly in place with a rubber seal against the base of the phototube. A steel planchet (1 in. in diameter by $\frac{5}{16}$ in.) could be introduced at the base of the cylinder by means of a slide to rest almost against the plastic scintillator, which was surrounded by a thin mylar reflector. The remainder of the apparatus consisted of a pre-amplifier, the high voltage supply, linear amplifier, and scaler—all available commercially.‡

Counting efficiency comparisons using calibrated sources of S^{35} and Ca^{45} were made between the system described and a lead-shielded, thin-mica end-window G-M tube§ (window less than 2 mg/cm² and 3.5 mm from the sample). Measurements were carried out on dried sources that varied from 0.001 to 0.1 microcurie. Duplicate aliquots counted repeatedly by each method did not differ more than 3% and no attempt was made to do absolute counting. In net counts per minute per microcurie, there was a standard deviation of no greater than 5% from the mean.



Discriminator curves of S^{35} and Ca^{45} using the plastic scintillator

The table indicates that under the conditions described the plastic scintillator was at least twice as efficient as the G-M tube. When the counting rate of the isotopes, normalized to a maximum of 100% for a discriminator of 5 volts, was plotted on semilogarithmic paper as a function of the discriminator bias, the electronic noise level as well as the background could be discriminated out, sacrificing only a small percentage of the counting efficiency (see graph). Since the values for S^{35} were obtained under conditions identical with those used to measure Ca^{45}, the maximum counting rate was not observed at the higher discriminator settings.

* * *

The authors wish to express their appreciation to B. A. Burrows and G. J. Hine for their advise and criticism during the course of this work, and to E. S. Dell for her technical assistance.

* Pilot Chemicals, Inc., Waltham, Mass.
† Dow Corning silicone 200.
‡ Atomic Instrument Co., Cambridge, Mass.
§ Tracerlab, Inc., Boston, Mass.

Plastic Scintillator vs G-M Tube

Detector	Ca^{45} (*net cpm/μc*)	S^{35} (*net cpm/μc*)
Plastic scintillator	57,228	44,789
G-M tube	21,847	13,900

BIBLIOGRAPHY

1. C. Lagiss, NUCLEONICS **14**, No. 3, 66 (1956)
2. G. J. Hine, B. A. Burrows, L. Apt, M. Pollycove, J. F. Ross, L. A. Sarkes, NUCLEONICS **13**, No. 2, 23 (1955)

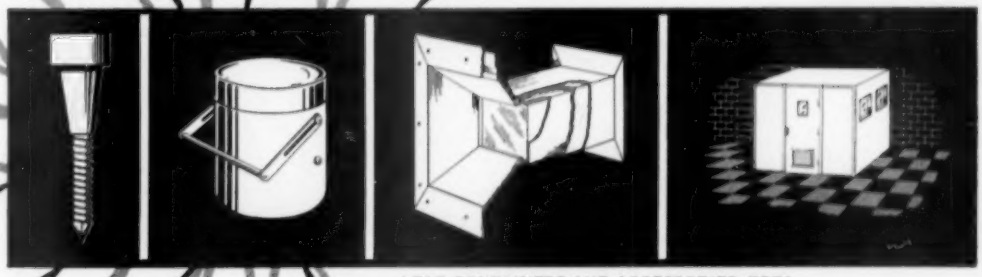
FROM LEAD-HEADED NAILS TO LEAD-LINED ROOMS . . . TO REACTOR SHIELDING

Webster* defines *complete* as ". . . with no part lacking . . . perfectly equipped or skilled" and it's a perfect description of *Ameray's Radiation Protection Products and Services.*

Need radioactive isotope handling materials? Look to Ameray for lead shipping and storage containers, fume hoods, high density concrete block, lead brick, Zinc Bromide or high density lead glass windows and related products.

Now, from one reliable source you can obtain every material, device and accessory needed to solve industrial and medical shielding requirements . . . Ameray's over 50 years of combined experience is the result of hundreds of X-ray and other high performance nuclear shielding installations already made throughout the world.

Ameray's skilled engineering-production team can also custom-build the unique units required to meet your most difficult applications from the smallest carrying container to full shielding for a reactor.



. . . . LEAD CONTAINERS AND ACCESSORIES, TOO!

Learn how these specialized services can help you; send for complete technical information about all of Ameray's dependable, safety-engineered products. Please request Booklet #22.

HERE'S REALLY COMPLETE SHIELDING SERVICE . . .

*Webster's new Collegiate Dictionary

ameray CORPORATION

ROUTE 46 KENVIL, NEW JERSEY

FOXCROFT 6-4100

N. Y. PHONE: BOWLING GREEN 9-0412

FIELD OFFICES IN LEADING CITIES

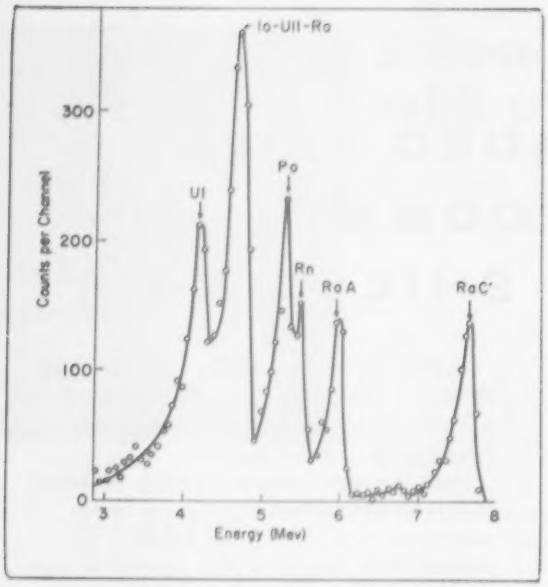


FIG. 1. Alpha spectrum of uranium mineral. Uranium content—0.1 % weight of mineral on disk—6 mg

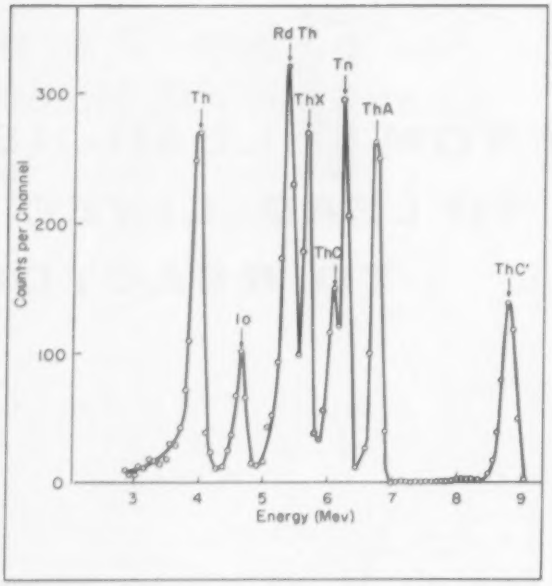


FIG. 2. Alpha spectrum of thorium salt mixed with nonactive sand

Analysis of U and Th Minerals by Alpha Spectrum

By U. FACCHINI, M. FORTE, A. MALVICINI, and T. ROSSINI
Laboratori CISE, Milano, Italy

The last few years have seen the development and wide application of radiometric methods for the study of uranium and thorium minerals, based on the measurement of their emissions and decay products.

The various methods may be divided into two groups:

1. Direct methods that use the specific radiations of uranium and thorium, such α-particles counted with photomultipliers or ionization chambers (*1*) and fission analysis, which consists of counting the fission of U^{235} by bombarding it with slow neutrons (*2*).

2. Indirect methods that are of wider use. These methods utilize the β- and γ-radiations emitted by the decay products. Generally speaking, a simple counting of β or γ is not suffi-

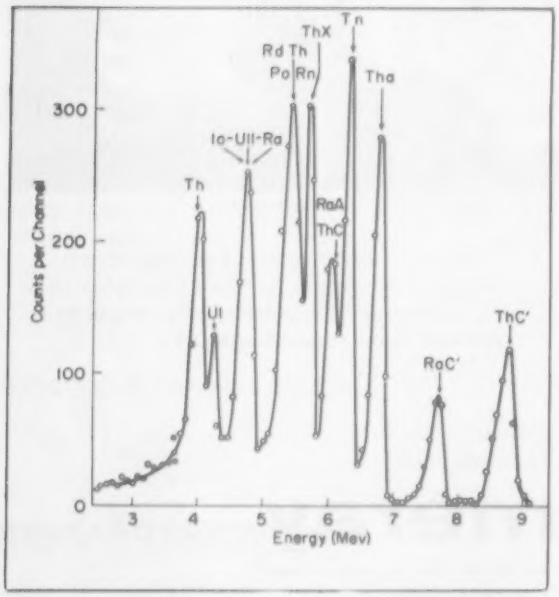


FIG. 3. Alpha spectrum of radioactive ore containing both uranium (0.7 %) and thorium (5.5 %)

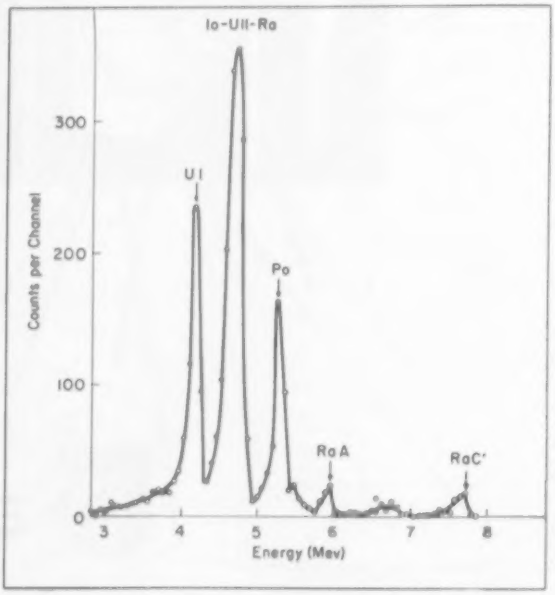
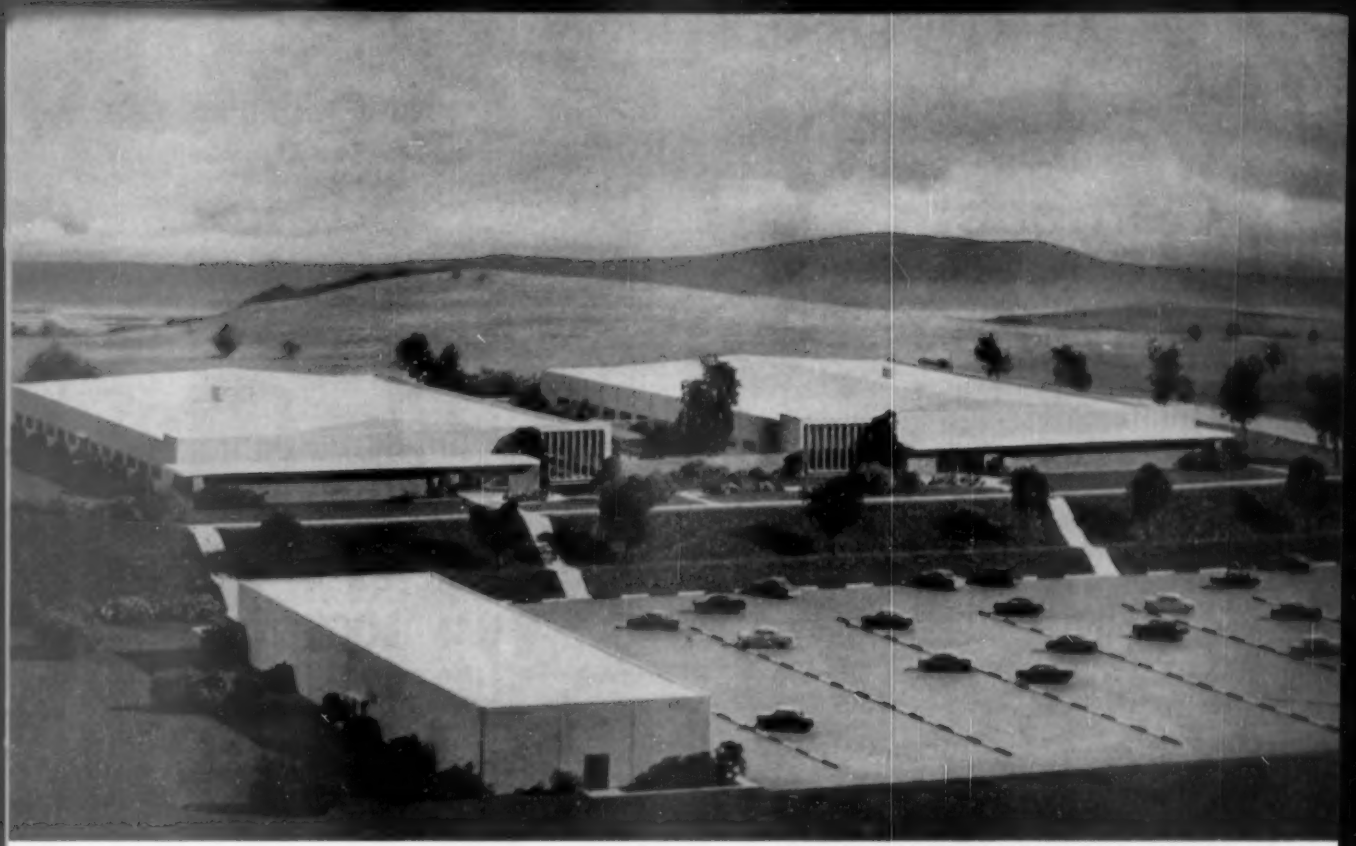


FIG. 4. Alpha spectrum of autunite sample showing radon escape



SCALE MODEL, NEW LOCKHEED RESEARCH CENTER AT PALO ALTO, CALIFORNIA
Here scientists and engineers are now working in modern laboratories on a number of highly significant projects.

LOCKHEED DEDICATES NEW RESEARCH CENTER

Scientists and engineers are now performing advanced research and development in their new Lockheed Research Center at Stanford University's Industrial Park, Palo Alto, California. In recent ceremonies marking its completion, the Research Center was dedicated to scientific progress.

First step in a $20,000,000 expansion program, it provides the most modern facilities for scientific work related to missiles and space flight. Significant activities are already being carried on in more than 40 areas, including upper-atmosphere problems, nuclear physics, hypersonic aerodynamics, use of new and rare materials, propulsion and advanced electronics.

Lockheed's expansion program has created positions on all levels for scientists and engineers in virtually every field of missile technology. Inquiries are invited from those possessing a high order of ability.

TRADE FAIR OF
THE ATOMIC INDUSTRY

Chicago · September 24-28

Senior members of the technical staff will be available for consultation at the convention hotel.
Phone FRanklin 2-9600

Lockheed

MISSILE SYSTEMS DIVISION

research and engineering staff

LOCKHEED AIRCRAFT CORPORATION

VAN NUYS · PALO ALTO · SUNNYVALE

CALIFORNIA

Completely Ruggedized

Compact Instruments

for—

Commercial, Civil Defense and Military Service

Model CH-720

SURVEY METER

Beta-gamma discriminating ionization chamber survey meter. Three ranges . . . 0-5, 0-50, 0-500 r/hr full scale. Sliding shield excludes beta. Complies with F.C.D.A. specifications CD V-720 for high range Civil Defense survey meters.

Model XA-100A

RADIAC DETECTOR CHARGER

Accommodates commercial, Civil Defense or military quartz fiber dosimeters using diaphragm type switch with barrel dia. .497" to .538" Requires no batteries . . . life virtually unlimited. Simple to operate under severe conditions. Light, ruggedized, pocket size.

Model CH-800

QUARTZ FIBER DOSIMETER WITH FRICTION CHARGER

Increases usefulness and flexibility of quartz fiber dosimeters by eliminating need for a separate charger. Can be slipped into pocket, clipped on belt.

Dosimeter range to customer's requirements. Meets military specifications.

SEE THEM ON DISPLAY! Visit Booth 153 — Atomic Trade Fair

Chatham Electronics

Division of Gera Corporation

Livingston, New Jersey
Branch Offices in Principal Cities

cient to deduce the uranium and thorium content of a mineral. In fact the number of β and γ emissions depends on the degree of radioactive equilibrium reached in the mineral. Moreover it is difficult to distinguish in these measurements whether the radiations originate from the uranium or the thorium family.

Other workers have developed the equilibrium counting method, which consists of recording for one sample both the β and γ activities. It is thus possible to ascertain in some cases whether a mineral contains uranium or thorium and to deduce the degree of radioactive equilibrium if it is a uranium mineral. A detailed analysis of this and other methods is given by Eichholz and others, and by Faul (*3*).

The method described here uses the spectral analysis of α particles emitted by minerals prepared in thin layers. The α particles of each element, as is well known, have characteristic and well defined energies. By studying the energy spectrum of the α particles it is possible to identify the various α-emitting nuclides present in the mineral. It is possible in this way to establish the quantity of uranium and thorium and the degree of equilibrium of the various radioactive nuclides.

Sample Preparation

The α-particle measurement technique is based on recent developments in the use of grid ionization chambers (*4*). These instruments provide a good degree of precision. By using a special filling mixture (argon 98%, nitrogen 2%) they can operate quickly and with great simplicity (*5*).

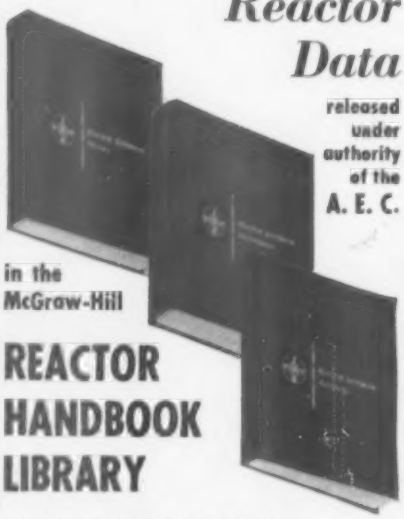
The chamber used by us is connected with a rotary pump and a tank containing the gas mixture. The collecting electrode is connected with an amplifier and a pulse analyzer.

The active sample is deposited as a thin layer on a metal disk, which is placed in the chamber and serves as a negative electrode. The chamber can be operated after a few minutes. The disk has a 14-cm diameter to provide a large sample emitting surface for examination.

The mineral layers were prepared in this way: A mineral sample is ground into fine powder. About 30 mg is suspended in water, to which an adhesive substance is added. (We have obtained good results using sodium silicate or gelatine with a weight ratio to the mineral just over 1/5.) While the suspension is kept in agitation, a known

Now--bringing you *Practical Reactor Data*

released under authority of the A. E. C.



in the McGraw-Hill

REACTOR HANDBOOK LIBRARY

3 volumes, 2475 pages, $37.50

For those seeking wider peaceful applications of atomic energy, here's a useful, ready-reference summary of many accomplishments of the AEC's nuclear energy program. Prepared by authorities, this Library contains much recently declassified information. While comprehensive in scope, material is condensed to essential practical engineering information needed in the design and development of facilities. It covers a wealth of information on reactor physics and radiation shielding, gives detailed engineering discussions of six different reactors, and treats extensively the materials of construction important in this field.

EASY TERMS
$7.50 in 10 days and $6 monthly

REACTOR HANDBOOK: PHYSICS
Discussion of reactor physics and nuclear-design data, including shielding theory and calculating techniques. *790 pp., 7½ x 10*

REACTOR HANDBOOK: ENGINEERING
Review of reactor technology, including basic reactor systems applicable to power development and a summary of experimental reactor designs. *1075 pp., 7½ x 10*

REACTOR HANDBOOK: MATERIALS
Data and background information on reactor materials; fuels and moderators, and shielding, structural, and miscellaneous materials. *610 pp., 7½ x 10*

10 DAY FREE TRIAL

McGraw-Hill Book Co., Dept. NU-F-O
327 West 41 St., New York 36, N. Y.

Send me the Reactor Handbook Library for 10 days examination on approval. In 10 days I will (check one) ☐remit full price of $37.50, or ☐remit $7.50 and pay balance at $6 a month. (Check below to examine for 10 days free any individual book in this Library.)

☐ Reactor Handbook: Physics—$12.00
☐ Reactor Handbook: Eng'g.—$15.00
☐ Reactor Handbook: Materials—$10.50

Print name.....
Address.....
City & Zone.....State.....
Company.....
Position.....

For price and terms outside U. S. write McGraw-Hill Int'l., N.Y.C. NU-F-O

volume is withdrawn and deposited uniformly on the disk to dry. A simple method of obtaining uniform layers is to drop the suspension on the disk, which has been previously wet, so that the drops expand by surface tension. The total weight of the mineral and the adhesive substance deposited on the disk may be varied between 3 and 20 mg and can be determined with less than a few percent error.

Measurements

Figure 1 illustrates the spectrum obtained with a sample of mineral containing 0.1% uranium in equilibrium with its decay products. Figure 2 shows the spectrum of a thorium salt in radioactive equilibrium.

The various products of U^{238} decay are easily identified from Fig. 1. The lines around 6.6 Mev are U^{235} decay products, An and AcC.

The lines of Fig. 2 are those of the various elements of Th^{232} family, except the line at ~4.8 Mev, which is believed due to the presence of ionium in the thorium salt. Presumably, the ionium, an isotope of thorium, has been separated with thorium from a mineral containing uranium.

Figure 3 shows a spectrum obtained from radioactive ore containing both uranium and thorium.

Radioactive Equilibrium

The radioactive equilibrium of the uranium family can be studied by examining the areas of the lines corresponding to the various nuclides.

The degree of equilibrium between uranium and ionium, and hence between uranium and radium, furnishes, as is well known, information about the age of the original mineral deposit. The intensity of the U^{238} line can be obtained directly from the spectrum.

The ionium and radium lines fall on the U^{234} line, and their intensity can be obtained by subtracting from the line at 4.8 Mev the area of the U^{234} line, which is equal to the U^{238} one. To obtain better precision it is convenient to study how the form of the spectrum in this energy region varies with the degree of equilibrium.

It is also interesting to study the areas of the lines of the radium decay products, namely Rn, RaA, RaC′, and polonium. It should be noted that the radioactive emanation from many minerals, and expecially when they are reduced to thin layers, may escape appreciably and thus upset the radioactive equilibrium between the radium

STANAT

2-High/4-High Combination Torque Arm Rolling Mill

1½&5x8 mill with roll change mechanism, designed to operate within glove box enclosure for processing pyrophoric materials at Argonne National Laboratory

Looking For a Versatile Mill To Roll Your Nuclear Materials?

Proven to be the ideal rolling mill for fabricating nuclear power fuel elements, this rugged, compact yet extremely versatile, high precision unit offers you a complete roll change in less than 15 minutes by means of a revolutionary, quick release mechanism. As a 2-high mill, or as a 4-high mill offering a choice of work roll diameters, it may be arranged with pay-off and recoiler stands and used as either a one-way or reversing unit. The mill is also widely used to process such materials as corrosion resistant, magnetic, and high temperature resistant super alloys.

Whether your requirements call for hot or cold rolling of wire shapes, hot or cold reduction of ingots and bars, or finish rolling of strip to less than 0.001", *you can now have at your command one mill to do all or a combination of these jobs.*

STANAT builds a complete line of 2-high/4-high mills ranging from ¾&4x6 to 2½&10x14 in addition to metal powder rolling mills, slitting lines, levelers, wire flattening mills and wire drawing equipment.

For detailed information, write today!

STANAT MANUFACTURING CO., INC.

471 37th Street, Long Island City, N. Y.

complete

in **16** *volumes*

PEACEFUL USES OF ATOMIC ENERGY

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE IN GENEVA, AUGUST 1955

This is the *only* definitive and unabridged report of the conference. More than 1,050 papers are included with the text of the oral presentations and the verbatim record of the discussion. The *American Scientist* has called these volumes "An undertaking of the first magnitude. . . . An outstanding effort. . . . (They) display a quality and authority far out of line with the modest price."

I The World's Requirements for Energy; The Role of Nuclear Power. 479 pp., $8.00.
II Physics: Research Reactors. 471 pp., $8.00.
III Power Reactors. 389 pp., $7.50.
IV Cross-Sections Important to Reactor Design. 357 pp., $7.50.
V Physics of Reactor Design. 545 pp., $9.00.
VI Geology of Uranium and Thorium. 825 pp., $9.00.
VII Nuclear Chemistry and the Effects of Irradiation. 691 pp., $10.00.
VIII Production Technology of the Materials Used for Nuclear Energy. 627 pp., $10.00
IX Reactor Technology and Chemical Processing. 771 pp., $10.00.
X Radioactive Isotopes and Ionizing Radiations in Medicine. 544 pp., $8.00.
XI Biological Effects of Radiation. 402 pp., $8.00.
XII Radioactive Isotopes and Ionizing Radiations in Agriculture, Physiology, and Biochemistry. 553 pp., $9.00.
XIII Legal, Administrative, Health and Safety Aspects of Large Scale Use of Nuclear Energy. 393 pp., $7.00.
XIV General Aspects of the Use of Radioactive Isotopes: Dosimetry. 305 pp., $6.50.
XV Applications of Radioactive Isotopes and Fisson Products in Research and Industry. 327 pp., $7.50.
XVI Record of the Conference. 203 pp., $5.00.

All volumes appear in a uniform 8½" x 11" format and are illustrated with charts, graphs, maps, and photographs

Come to the United Nations display at the 1956 Trade Fair of the Atomic Industry. Booth 428.

International Documents Service

COLUMBIA UNIVERSITY PRESS

New York 27, New York

and its decay products (*5*). In this case the analysis of the α spectrum provides useful information on the diffusion properties of radon in the original rock and in the thin layer.

Figure 4 shows the spectrum obtained from a sample of autunite. The low intensity of the lines of RaA and RaC′ indicates that radon is strongly escaping from the thin layer. The high intensity of the polonium line shows, on the other hand, that the radon escaping from the original rock was not important.

It is desirable to prepare layers in such a way as to prevent escape of the radioactive emanation from the layer. The best results were obtained by covering the layer with a thin film of sodium silicate and cooking it in a stove to vitrify the silicate. An increase with time of the intensity of the lines of Rn, RaA and RaC′ indicates the gradual re-establishment of the radioactive equilibrium in the layer.

Near equilibrium, the measurement of the intensity of the lines of RaA and RaC′, which are well separated, permits evaluating the radium content with good precision.

In the case of thorium, the following remarks can be made:

1. Because of the short life of the thorium decay products, with respect to the time of deposit formation, the minerals containing thorium are generally in radioactive equilibrium.

2. Because of the very short life of Tn (54.5 sec) it does not generally escape from the minerals.

Uranium-Thorium Ratio

The examination of the spectral lines may indicate to which of the two radioactive families the α activity is due, and, in the presence of both, the ratio between uranium and thorium. For this purpose it is necessary to know the respective areas of the lines of U^{238} and of Th^{232}.

From what has been said about the equilibrium of the thorium family, and taking into account the decay sequences of the thorium family, we can assume that the line of Th^{232} has an intensity equal to $\frac{3}{5}$ of the 8.8-Mev line of ThC′, which is very easy to measure since it is well separated in the spectrum. With our resolution, the U^{238} line generally overlaps the line of Th^{232}. The intensity of the U^{238} line can be deduced as the difference between the total line obtained in the region of 4–4.2 Mev and the ThC′ line multiplied by 1.5. The abundance ratio between the two

—FROM STOCK—

Reactor Grade

YTTRIUM

OXIDE

Irradiation Grade

THULIUM OXIDE

ALSO

GADOLINIUM, SAMARIUM,

and other lanthanon oxides in purities up to 99.9%. Write for latest price list and informative descriptive brochure.

Inquiries concerning Sintered Shapes, Encapsulation, and Rare Earth Salts and Metals invited. R & D Consultants.

Prompt Quotations!

Buy Direct:

PRIME PRODUCERS OF PURE RARE EARTHS

ST. ELOI CORP.

Research Laboratories, Inc., Subsidiary

Dept. N

NEWTOWN, OHIO

Phone Cincinnati - LOcust 1-6463

DESIGNERS

ENGINEERS

PRODUCTIONEERS

INVESTIGATE

the merits of

Westlake

ULTRA-ETHYLUX

The New, Special Service Super-Polyethylene

- 4 times greater rigidity,
- Stability at much higher temperatures,
- Superior di-electric properties,
- Same high impermeability to neutron penetration,
- Same relative low cost

. . . when compared to normal Polyethylene

Test samples, preliminary data and technical service supplied in response to your detailed inquiries.

Westlake plastics co.

144 W. Lenni Road, Lenni Mills, Penna.
In Lower Delaware Valley, U.S.A.
New Phone No.: MEdia 6-5170

families is determined with sufficient precision when the ratio between the activities of U and Th is 0.1–10.

Uranium and Thorium Content

With the sample preparation and measurement techniques described earlier, the quantity of the mineral in mg that is deposited on the disk can be determined within a few percent.

Having determined with similar precision the area of a line in which we are interested, we can at once deduce the quantity of the corresponding nuclide contained in the mineral, as the number of α particles emitted per mg per minute by uranium or thorium is well known. The useful solid angle is ½ and the yield of the chamber can be assumed equal to 1. In cases where the area of the line must be determined with great exactness, it is well to correct it for the self-absorption of the α particles in the layer and to repeat the measurement with various layer thicknesses. In our measurements these corrections are but a few percent.

To give an idea of the intensity obtainable, under our conditions a mineral containing 1% uranium in equilibrium emits over all the lines ~300 pulses/min, with a layer of 10 mg of mineral on the whole disc.

By increasing the thickness of the layer, this number increases but with a corresponding worsening of the resolution of the lines that are broadened as a result of the self-absorption.

Taking each case individually, a compromise between intensity and resolution is convenient, and it may be useful to choose rather thick layers to determine the intensity and very thin layers to study the various lines and the equilibrium.

Under our conditions it is possible to examine samples up to a few units per 10,000 of uranium and thorium with a measurement time of a few hours. These samples emit 5–10 pulses/min.

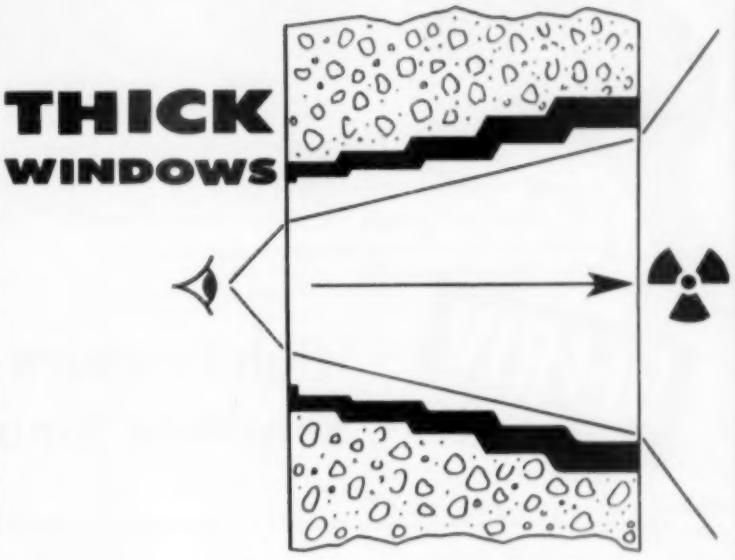
* * *

Thanks are due to G. Bolla, B. Ferretti, and A. Cacciari for their interest and useful discussions.

BIBLIOGRAPHY

1. H. H. Nogami, P. M. Hurley, *Trans. Am. Geophys. Union* **29**, 335 (1948); D. H. Peirson, *Proc. Phys. Soc.* **B64**, 876 (1951)
2. U. Facchini, L. Orsoni, *Il Nuovo Cimento* **6**, 241 (1949); W. W. Happ, J. L. Horwood, *Science* **115**, 622 (1952); I. Joliot Curie, M. Farassi, *Compt. Rend.* **232**, 959 (1951)
3. G. G. Eichholz, J. W. Hilborn, C. McMahon, *Can. J. Phys.* **31**, 613 (1953); H. Faul, "Nuclear Geology" (John Wiley & Sons, Inc., New York, 1954)
4. B. Rossi, H. Staub, "Ionization Chambers and Counters" (McGraw-Hill Book Co., Inc., New York, 1949)
5. C. Facchini, A. Malvicini, NUCLEONICS **13**, No. 4, 36 (1955); **14**, No. 5, 96 (1956)

new designs
for radiation viewing



● **WIDE ANGLE VISION . . .**
On the centerline, 10 inches from a typical 3 foot window, the field of view is 50° vertical and 60° horizontal. The extreme limit of view is 120° vertical and 140° horizontal.

● **STANDARD WINDOWS**
are available for wall thicknesses of 36, 42, 48 inches. Special windows to 6 feet.

● **ANY DENSITY**
2.7 3.3 3.5 3.8 4.0 4.2 4.8 5.2 6.2

● **REPLACEABLE HOT-SIDE COVER GLASS**

● **LOWER COST** Achieved by new design and new glasses.

● **GLASS LOW-REFLECTION COATED FOR OIL IMMERSION**

Originators of
Hi-D LEAD GLASS

WRITE FOR BROCHURE GS-5

PENBERTHY INSTRUMENT CO.
4901 6th AVE. SOUTH · SEATTLE 8, WASH.

Defriv: a simulated map war game involving defensive operations along a river line under conditions of simulated atomic warfare. Map battles, fought by groups of field-experienced officers, evaluated by a team of scientists and officers, improve our Army's ability to wage modern war—a typical example of the work of Combat Operations Research Group.

- PHYSICISTS
- MATHEMATICIANS
- *and other* SCIENTISTS

will find in CORG a small but growing research group, with freedom to think and limitless creative opportunity. Varied scientific disciplines, good living conditions, and all usual benefits, make CORG a "good place to work." Find out for yourself.

for information, write to:
Dr. F. C. Brooks, *Director*
COMBAT OPERATIONS RESEARCH GROUP
Fort Monroe, Virginia

TECHNICAL OPERATIONS
INCORPORATED

FIG. 1. Ionization chamber

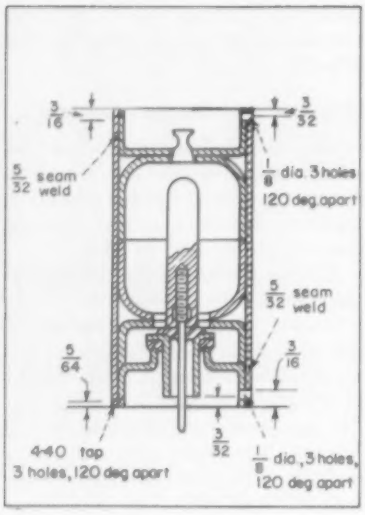


FIG. 2. Construction of chamber

High-Pressure Al-Walled Sensitive Ionization Chamber

By P. A. DUFFY
X-Ray Division
Westinghouse Electric Corporation
Baltimore, Maryland

We have developed an ionization chamber with 60 times the output of an air-equivalent chamber of the same volume. Along with sensitive, high-impedance amplifiers already in use, this makes the simple, stable ionization chamber a more sensitive radiation detector.

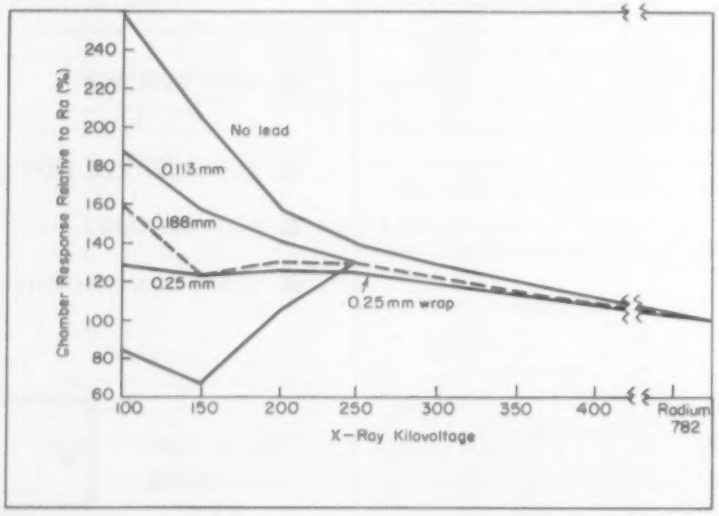


FIG. 3. Spectral response to X-ray photons with various amounts of lead filtration. Curves have been normalized to make response to radium gamma photons appear equal, although this is not actually true

Our increased sensitivity comes from the use of high-pressure argon in an aluminum-walled chamber. In a field of cosmic-ray particles argon produces 1.4 times the ionization of air at the same pressure—a ratio about equal to their density ratio. A factor of 17 is gained by pressurizing to 17 atmospheres. A third improvement is that electrons emitted from the walls of our small chamber cause a specific ionization 2.5 times as high as that produced in an unlimited volume of argon by the same radiation.

Chamber Design

Figure 1 and 2 show chamber. The steel outer vessel is lined with aluminum. The central collector is an aluminum rod. The guard ring is a small steel cylinder shielded internally by the aluminum lining. The seals are Kovar-to-glass.

Figure 3 shows the spectral response of the chamber to X-rays with various thicknesses of lead wrapping for filtration. With 0.25 mm of lead the departure from a flat response is less than 12% everywhere in the useful spectrum. This filtration reduces the response to radium gammas by 25%. Complete cutoff occurs at 55 kev. Photons below this energy do not penetrate the chamber wall.

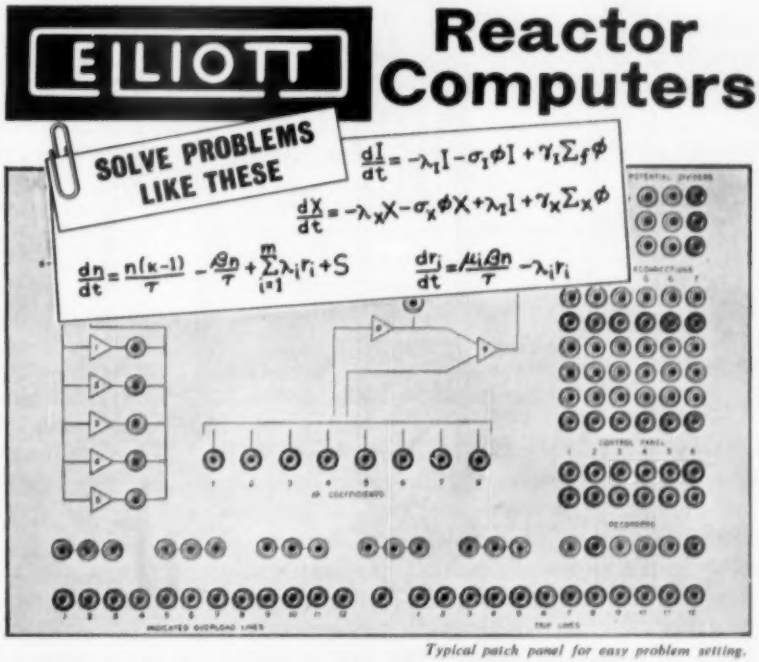
Voltage, Temperature

Saturation voltage and temperature are important in the operation of the chamber. At high radiation levels the ion density and thus the tendency to recombine are high. Since most of the positive ions are formed near the shell, where most of the gas is, they have shorter paths to travel when they are collected at the shell, rather than at the central electrode. For a true response, a lower saturating potential is possible when the shell is negative than when the opposite polarity is used. The diameter of the central electrode also influences the saturation voltage.

Temperature affects the insulation resistance because of the properties of the glass. With an increase from 68° to 115° F insulation resistance between guard ring and collector decreases from 5×10^{14} to 2.5×10^{14} ohms, but operation at even higher temperatures than this is possible if the external circuit provides for it.

The unit has been used successfully in devices for dose-rate measurements in the range 1–50,000 mr/hr. It is rugged, durable, and has proved to be very stable.

Staplex
NEW
HI-VOLUME
AIR SAMPLER
accurately samples the air for
radioactive material, particulate matter, etc.
Hundreds used in Atomic Energy tests, and by Industries employing, developing and manufacturing nuclear products . . . Literally "inhales" an entire area with unparalleled speed and accuracy . . . Particles as small as 1/100th a micron in diameter have been accurately sampled by this unit . . . Portable . . . Designed for indoor and outdoor use . . . Indispensable for series or unit tests. 24 V, 110 V, & 220 V models available.
For details about this new scientific method
THE Staplex CO.
AIR SAMPLER DIVISION
783—5th Ave., Brooklyn 32, N.Y.


ELLIOTT
Reactor Computers
SOLVE PROBLEMS LIKE THESE
$\frac{dI}{dt} = -\lambda_I I - \sigma_I \phi I + \gamma_I \Sigma_f \phi$
$\frac{dX}{dt} = -\lambda_X X - \sigma_X \phi X + \lambda_I I + \gamma_X \Sigma_X \phi$
$\frac{dn}{dt} = \frac{n(k-1)}{\tau} - \frac{\beta n}{\tau} + \sum_{i=1}^{m} \lambda_i r_i + S$
$\frac{dr_j}{dt} = \frac{\mu_i \beta n}{\tau} - \lambda_i r_i$

Typical patch panel for easy problem setting.

Elliott Brothers (London) Limited provide machines specifically designed for the study of a simple reactor or a complete power producing plant. Reactor Simulators for use by Universities and Colleges in the training of nuclear engineers can also be provided.

- Normally operate in real time.
- Simple problem patching and coefficient setting.
- Facilities for transport lag simulation.
- Electromechanical plug-in multipliers operate from standard computing amplifiers.

NUCLEAR DIVISION, ELLIOTT BROTHERS (LONDON) LTD., CENTURY WORKS, LONDON, S.E.15, ENGLAND

NUCLEAR ENGINEERING

Valves and Corks to Seal Reactor Shields

By C. V. MOORE
Knolls Atomic Power Laboratory
General Electric Co.
Schenectady, N. Y.

Many components of reactors must be periodically removed and replaced with new or reconditioned parts. Fuel elements suffer depletion; breeder elements must be reprocessed; control rods lose their effectiveness. Many parts must be replaced for experimental purposes or after radiation damage.

The hole through which a component is removed must be tightly sealed to the servicing machine and protected by shielding. If the machine is designed to be removed from the reactor to discharge the removed component or pick up a replacement, there is a problem of sealing and shielding the hole in the reactor. This is similar to the problem of sealing and shielding the opening in the machine. With water-cooled reactors, this hole is often sealed by a column of water that also functions as shielding, but liquid-metal-cooled reactors generally require some sort of mechanical sealing device similar to that used for servicing equipment.

Many different sealing methods are available. The choice is dictated by circumstances of the particular application. The factors of most importance are usually: size and weight limitations of equipment, desired speed of operation, size and shape of reactor components to be carried, thickness and type of shielding required, cost of machine failures and downtime for repairs, quality of maintenance, frequency of use of equipment, permissible leak rates, and characteristics of any coolants present.

Sealing devices can be divided into two general categories—corks and valves, which in turn can be subdivided into a number of different types.

Corks

Corks are plugs of various sizes and shapes used to stop up the hole in the service machine. The cork must be equipped with some type of seal, such as O-rings or piston rings, must be long enough and made of suitable materials

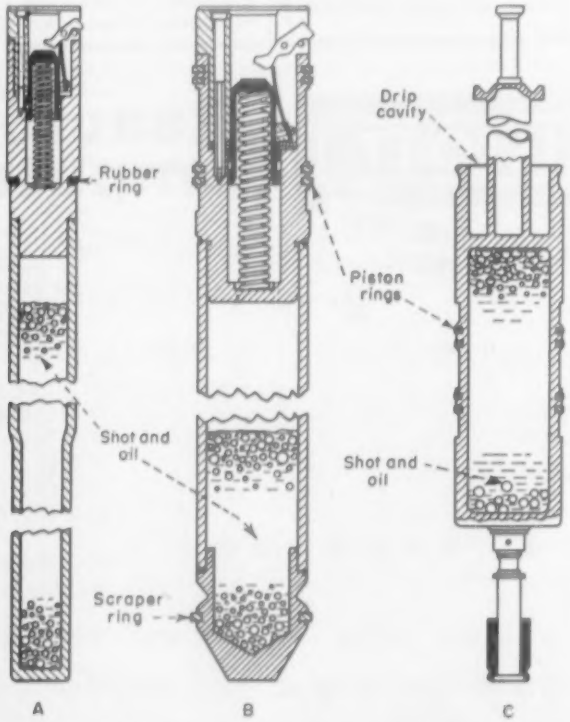


FIG. 1. Three types of shot-and-oil-filled corks for reactors and service equipment. Steel shot shields against gamma rays; oil shields against neutrons. Cork A is sealed by shaped rubber ring just below step in cork. Ring seats against a shelf in mating hole. Step prevents streaming of radiation along gap between cork and hole. Piston rings seal cork B. Pressurized inert gas between rings leaks in both directions along cork and provides fully effective gas seal. Scraper ring removes foreign material as cork is inserted. Type C is also sealed with piston rings and inert gas. Cavity at top catches radioactive coolant that drips from grapple of servicing machine

CORKS . . .

. . . have these advantages

- *They are mechanically and geometrically simple.*
- *Lower ends of servicing machines usually need no complicated mechanisms.*
- *Service machine diameters can be kept to a minimum.*
- *Sealing surfaces are readily accessible for repair and maintenance.*

. . . and these disadvantages

- *If lifting grapples or latches fail, corks may drop or be blown out.*
- *Sealing surfaces are exposed to dirt and damage in handling.*
- *Disposal of cork must be provided during transfers through its hole.*
- *Significant pressure differential across a cork requires latching mechanisms.*

VALVES

. . . have these advantages

- *They readily can be made fail safe.*
- *Sealing surfaces are protected.*
- *There is no disposal during opening.*
- *They are easily designed to work against a pressure differential.*

. . . and these disadvantages

- *They are likely to be complicated.*
- *Space needs are greater than for corks.*
- *Sealing surfaces may have poor accessibility for maintenance and repair.*
- *Their complicated designs are prone to failure due to warpage, wear, dirt, etc.*

NOW! FOR THE FIRST TIME

DIRECT WRITING CONVENIENCE WITH PHOTOGRAPHIC ADVANTAGES!

Introducing **Century ELECTROGRAPH MODEL 420**

ELECTROPHOTOGRAPHIC RECORDING OSCILLOGRAPH

You Asked For This!

ONLY THE REVOLUTIONARY CENTURY ELECTROGRAPH OFFERS THESE FEATURES

- ***Permanent instantaneous oscillograms***
- ***Eliminates need for messy liquid chemicals***
- ***No darkroom required***
- ***Automatic continuous dry processing***
- ***View oscillogram while recording***
- ***Utilizes sensitive light-beam galvanometers***
- ***Up to 24 traces on eight inch paper***
- ***Traces can overlap***
- ***Precision timing lines***
- ***Low power consumption***

Century's engineers are the first to accomplish the long dreamed-for wedding of photographic recording and completely automatic dry processing to eliminate the need for costly darkroom facilities and liquid developing, rinsing and fixing.

The greatest advancement in the technique of multi-channel oscillograph recording in over 20 years, the CENTURY ELECTROGRAPH is essentially a direct-writing recording oscillograph utilizing the RADICALLY new technique of Electrophotography combined with light-beam galvanometers.

NOW investigate CENTURY ELECTROGRAPH—the most modern approach to simplified oscillographic recording — when planning your instrumentation program whether for research, engineering, test, quality control, process control, or any other analog recording requirement.

COSTS NO MORE THAN OLD-FASHIONED METHODS

Century Electronics & Instruments, Inc.

1333 NO. UTICA, TULSA, OKLAHOMA

For further information, call on our nearest representative:

EXPORT OFFICE: 149 BROADWAY, NEW YORK CITY — TEL.: BARCLAY 7-0562

PHILA.-WASH. AREA	N.Y.-NEW ENGLAND AREA	MIDWEST AREA	TEXAS-N. M. AREA	ARIZONA AREA	SO. CALIF. AREA	NO. CALIFORNIA
4447 N. BODINE ST.	29-46 NORTHERN BLVD.	363 W. FIRST ST.	5526 DYER ST.	3696 KAKER PL.	40 SO. LOS ROBLES	2015 EL CAMINO REAL
PHILADELPHIA 40, PA.	LONG ISLAND CITY 1, N. Y.	DAYTON 2, OHIO	DALLAS, TEXAS	TUCSON, ARIZONA	PASADENA 1, CAL.	REDWOOD CITY
TEL.: MICHIGAN 4-1822	TEL.: STILLWELL 4-7128	TEL.: FULTON 9292	TEL.: EMERSON 6716	TEL.: 7-1581	TEL.: RYAN 1-9663	TEL.: EMERSON 6-8214

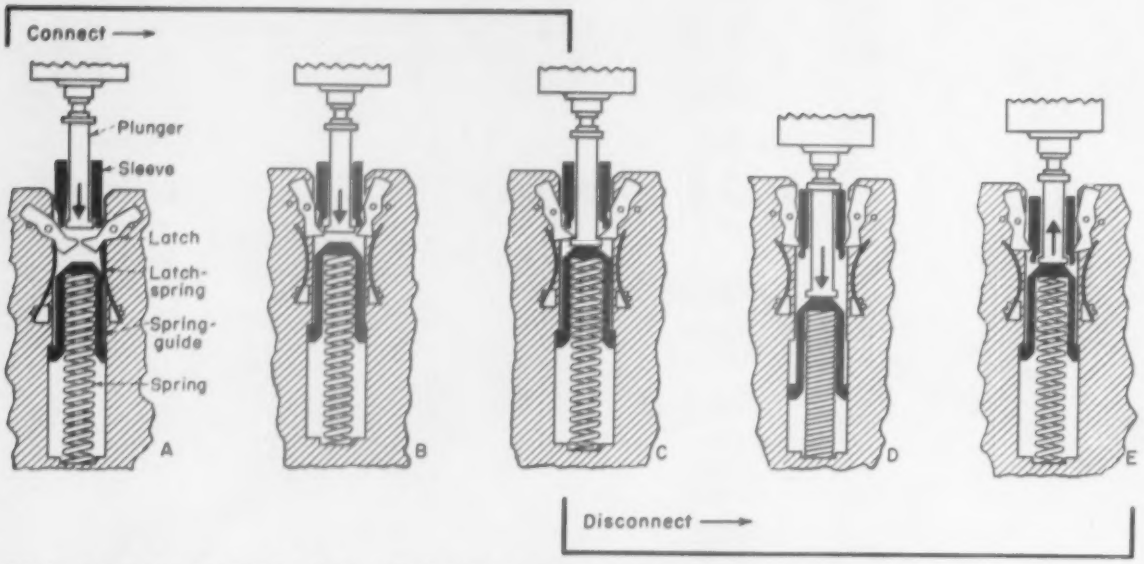


FIG. 2. Push-pull latch of cork C in Fig. 1. Cork latches in place by insertion into hole and disconnects when pushed farther down and then withdrawn. To connect, stem is advanced until catches in hole grasp rim at bottom. To disconnect, plunger is advanced until sleeve is forced between catches. Then stem is withdrawn as in step E, catches sliding on sleeve

to prevent excessive radiation from passing through the hole, and must fit quite snugly into the hole in the machine to prevent streaming of radiation through the gap surrounding it. Several examples of reactor and service equipment corks are shown in Figs. 1–3.

One of the major problems in the use of corks is how to remove the cork when material is to be brought through the hole. One method is to pull the cork up into the servicing machine. The corks shown in Fig. 1 operate on this principal. It is necessary to remove the cork from both machine and reactor. With the cork designs of Fig. 1, both of these removals are accomplished at the same time by means of the push-pull latch located in the tops of corks A and B and the sleeve-and-plunger de-

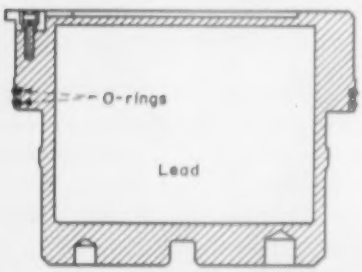


FIG. 3. Typical cork sealed with rubber O-rings. Poured lead provides shielding

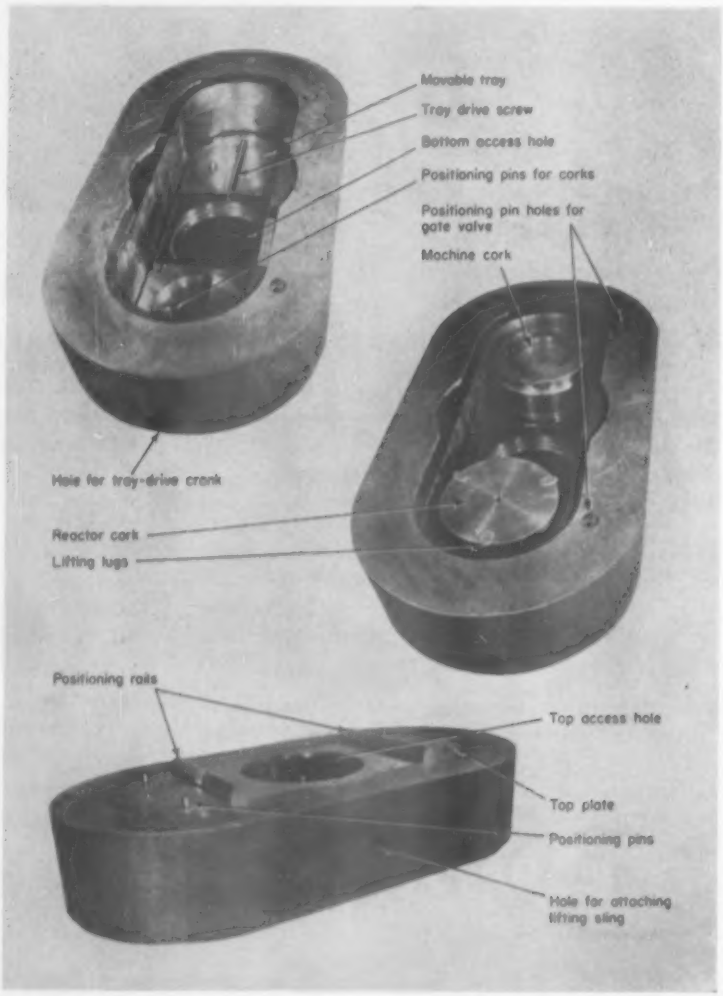
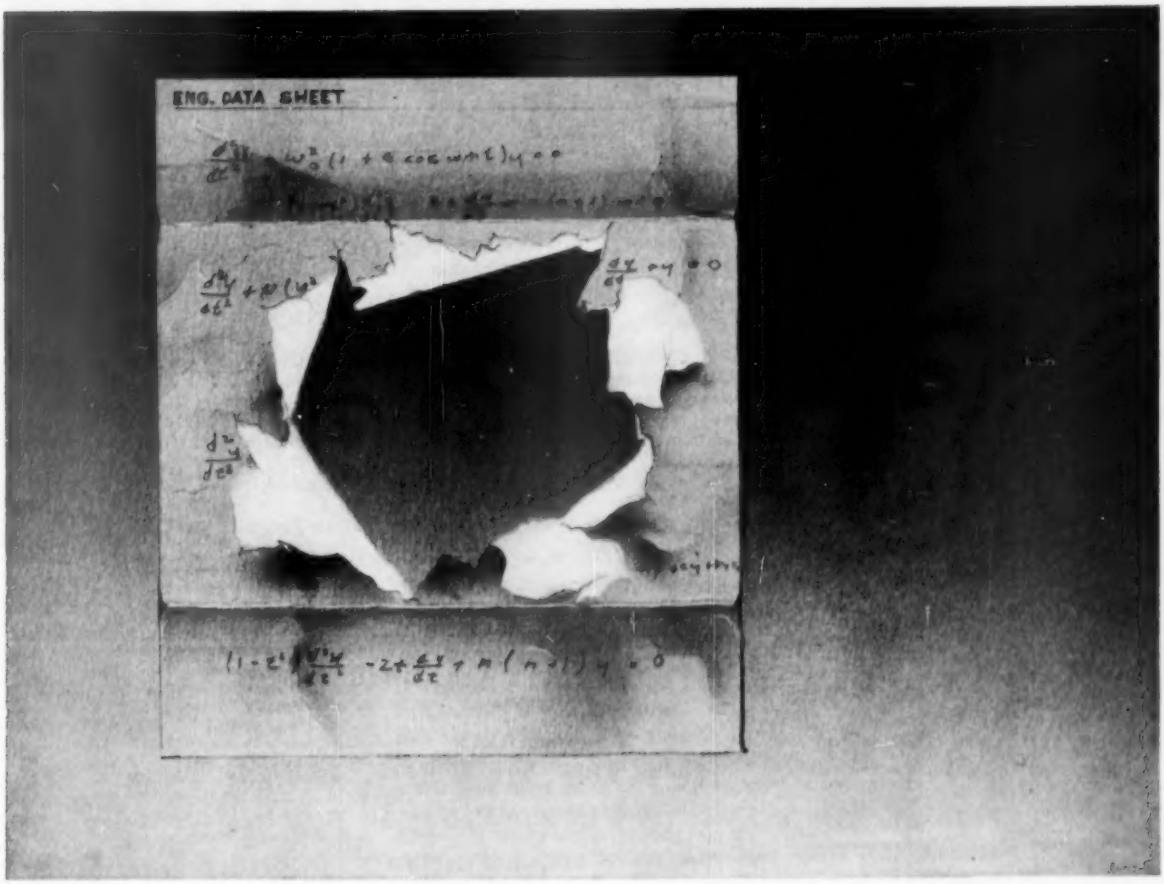


FIG. 4. Gate valve (right) stores both machine cork and shield cork out of the way while objects are transferred through holes they seal. Operation is shown in Fig. 5



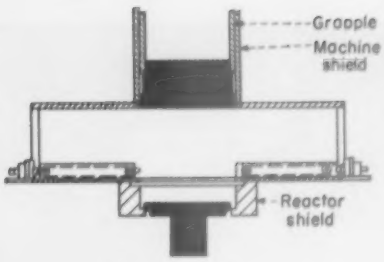
Break Through The PROBLEM Barrier

Making it possible for Engineers to break through the problem barrier is our most important project. Since our Company's inception, constant attention to the human engineering factor has brought about such advantages as High Speed Servos, Automatic Extended Readout with push-button control, Problem Checks, Electronic Multipliers, Servo Voltmeters, Resolvers and Function Generators, etc. Our standard production has the further advantage of actual time in the field before being announced as "new." Just one more reason why you can always look to PACE for Progress in Analog Computing Systems, for reliability, stability and overall economy. For details, write Electronic Associates, Inc., Dept. N-9, Long Branch, New Jersey.

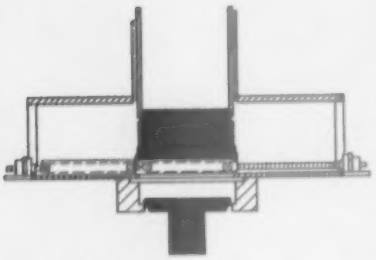
ELECTRONIC ASSOCIATES Incorporated

EAI SETS THE P PRECISION A ANALOG C COMPUTING E EQUIPMENT

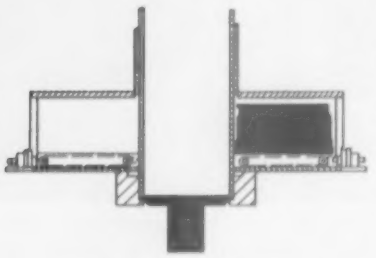
LONG BRANCH, NEW JERSEY



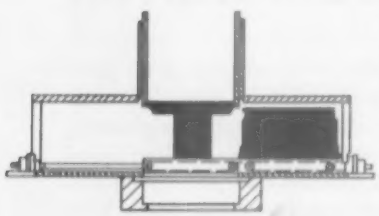
Both corks in place



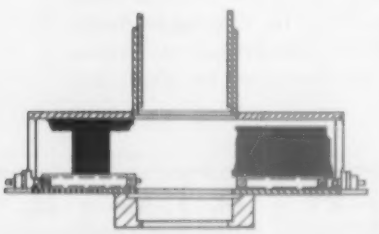
Machine cork lowered to its tray



Grapple seizes reactor cork



Reactor cork on tray



Both corks retracted

FIG. 5. Operation of gate valve assembly of Fig. 4

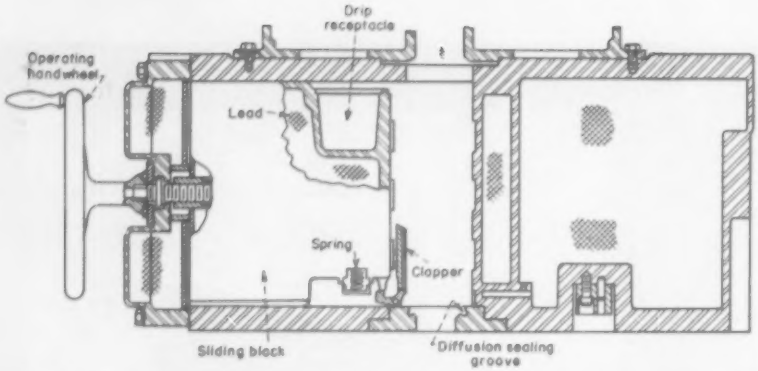


FIG. 6. Sliding-block valve in open position. Operating handwheel moves lead-filled block that furnishes shielding. When block is withdrawn, cam bears on lever attached to clapper to open hole in reactor shield. When block slides forward, spring bears on clapper to seat it in hole and provide sealing against fluid leakage. Inert gas leaks both ways from groove around clapper seat to provide diffusion seal. Receptacle catches fluid dripping from parts removed from reactor

vice at the bottom of cork C. Operation of this latch is shown in Fig. 2. This latching device has undergone over 1,000 operating cycles under various simulated service conditions and has performed very satisfactorily.

An alternate method of disposing of the corks is by means of a gate valve arrangement such as that shown in Figs. 4 and 5. The valve provides a means for drawing the corks to one side on movable trays on which the corks are deposited by the machine grapple.

Valves

Valves differ from corks mainly in that the moving components are retained at all times in the immediate vicinity of the sealed opening. Valves may be produced in a great variety of designs. Most are from one of three basic types—sliding valves, rotary valves, and doors.

Sliding valves operate by sliding a block or wedge into the opening to be closed. Figure 6 illustrates one example.

Rotary valves, on the other hand, operate by rotating a slab with a through-hole in it into positions so the through-hole is either lined up with the reactor hole or rotated away (Fig. 7).

Door-type valves consist of slabs opened by swinging to one side around hinges located in the plane of the opening. In one example, two doors are used to minimize the size of the clearance space into which the doors open. The doors are stepped to reduce radiation transmission through the crack. This type of valve is most useful where the object carried has a rectangular outline and the thickness of shielding required is small compared to the width of the machine opening.

* * *

Most examples given were adopted from actual equipment designed in connection with the Submarine Intermediate Reactor project conducted by the General Electric Co. at the Knolls Atomic Power Laboratory for the U. S. Navy and AEC. Among the many individuals who contributed to the design of this equipment are these: J. R. Payne, C. S. Hofmann, W. L. Gaya, K. G. Carney, R. Sertl, S. A. Shuler, J. D. D'Allesandro, J. R. Prout, J. C. Larson, D. F. Wood, J. S. Greacen, R. Durante, J. W. Reid, R. H. Horton.

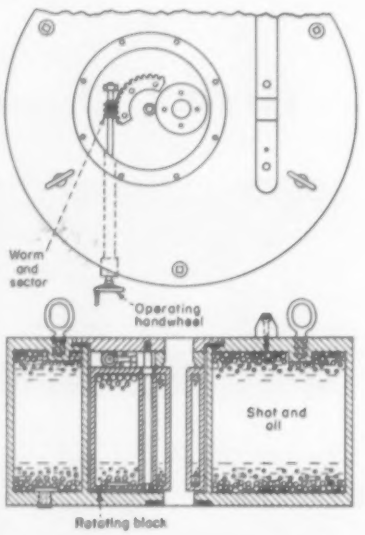


FIG. 7. Rotary valve operates by rotating slab with through-hole into positions in which through-hole is either lined up with reactor hole or rotated away from it. Rotary motion is induced from a hand-driven shaft by means of a worm gear and pinion. Shaft supporting slab is fixed at only one end to permit easy removal for maintenance

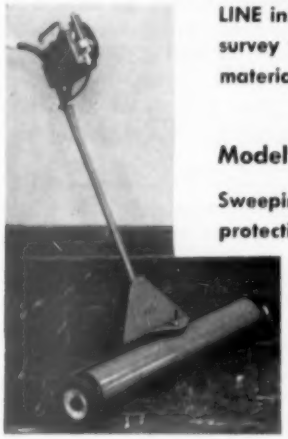
EBERLINE Instrumentation for the Health Industry . . .

Model E-112B GEIGER COUNTER

Here is the ideal Beta-Gamma Survey Meter for Industrial Health Technicians. It is a well balanced, highly stable, extremely accurate, four pound instrument. Frontal mounted probe permits handling of Survey Meter with one hand leaving free hand for other duties. Internal construction consisting of replaceable power supply and trigger-amplifier units permits Technician to maintain instrument while inexpensive components undergo repair. Capital equipment expenditures are reduced by eliminating standby Survey Meters.

MINE EVALUATION INSTRUMENT Model E-200A

Combining the ideal features of the Model E-112B with six scale ranges, and connections for a remote area radiation monitoring probe and a ten millivolt recorder, this compact, rugged, and easily maintained instrument incorporates the usual plug-in design and simplicity found in all EBERLINE instruments. It is highly recommended for radiological survey work in all industrial installations using radioactive materials and sources.



Model FM-1 FLOOR MONITOR

Sweeping a 24-inch width, this prime industrial health protection instrument rapidly monitors floor surfaces where Beta-Gamma radioactive contamination is present. The steel encased lead shield reduces the direct and scattered radiation from other than floor surfaces and with 45° forward rotation, permits exposure of detector tubes to frontal areas for monitoring near baseboards and other wall surfaces. Models E-112B and E-200A Geiger Counters are integral units of this basic monitor which increases the productivity of Industrial Health Technicians.

PORTABLE SAMPLE ANALYZER

Model SA-3

Beta-Gamma activity in soil, air, and water samples are determined on-the-spot with this fast, efficient, and extremely portable radio-metric assaying counter. Designed and developed for use where immediate results are required, scientific principles have been combined with field tested construction to insure accuracy and dependability.

This advanced Engineering Company offers its experience, knowledge, and facilities for the solution of Health Instrumentation problems

EBERLINE INSTRUMENT DIVISION
of Reynolds Electrical and Engineering Co., Inc.

805 Early Street
P. O. Box 279
SANTA FE, NEW MEXICO

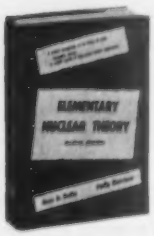
The first engineering examination of nuclear reactors

THERMAL POWER from NUCLEAR REACTORS

By A. STANLEY THOMPSON and OLIVER E. RODGERS, both of Studebaker-Packard Corp.

With a practical, problem-solving approach, this work gives a thorough survey of reactor design. Its prime purpose is to present some new viewpoints which have arisen from the necessity to solve design problems for what has been called the "new generation of reactors." Emphasis is on numerical methods and dimensional analysis and on non-linear kinetics of reactor behavior. Though the authors assume some knowledge of physics, the chapter on nuclear consideration gives a concise picture of nuclear fission suitable for review and orientation to advanced modern thinking.

1956 229 pages Illus. $7.25



Ready now the up-to-date 2nd edition

ELEMENTARY NUCLEAR THEORY

By HANS BETHE, Professor of Physics, and PHILIP MORRISON, Professor of Physics and Nuclear Studies, both of Cornell University

Every chapter has been expanded and new chapters added in the new edition of this famous work. Its material covering the use of polarized beams and the newer methods of nuclear radius measurement can be found nowhere else in book form. Growth of meson physics and meson field theory are both discussed. No other book sets forth so compactly on an elementary level, the basic theory of nuclear forces, structures, and reactions.

1956 274 pages Illus. $6.25

Mail this coupon today for 10-day FREE trial copies

JOHN WILEY & SONS, Inc. N–66
440 Fourth Ave., New York 16, N. Y.

Please send me the book(s) checked to read and examine ON APPROVAL. In 10 days I will return the book(s) and owe nothing, or will remit the full purchase price(s), plus postage.

( ) THERMAL POWER FROM NUCLEAR REACTORS, $7.25
( ) ELEMENTARY NUCLEAR THEORY, $6.25

Name . . . . . .
Address . . . . . .
City . . . . . Zone . . State . . . .

( ) SAVE POSTAGE! Check here if you ENCLOSE payment in which case we pay postage. Same return privilege; refund guaranteed.

TECHNICAL ADVANCES

10-Mev Van de Graaff By Tandem Swindle The 7–14-Mev energy region will become accessible to high-precision Van de Graaff accelerators as a result of the implementation of the "swindletron" concept. One accelerates negative ions from ground to a high positive potential. There they pass through a foil that strips them of the excess electron and one more making them into positive ions. These then can be accelerated through the same potential to a total energy twice as great.

A small swindletron has been built at Berkeley. But a 34-ft-long 8-ft-diameter 10-Mev tandem machine to be built by High Voltage Engineering Corp. for nuclear research at Chalk River will be the biggest ever.

Early Enrichment→ Primeval Piles Natural chain-reacting systems may have been a feature of early geologic times. Certainly the likelihood is improved by the greater U^{235} content of natural uranium in those days. The fact that the half-life of U^{235} (7.1×10^8 yr) is less than that of U^{238} (4.5×10^9 yr) means that present-day uranium is depleted by comparison with its primordial version. Thus, while present day "enrichment" is only 0.7%, 1.4-billion years ago it was 2.3%, and 2.8-billion years ago it was an impressive 7%. Corresponding thermal η values (number of neutrons emitted per neutron absorbed in natural U) are 1.32 at present, 1.77 at 1.4-billion years ago, and 1.98 at 2.8-billion years ago.

Radiogeochemist P. K. Kuroda of the University of Arkansas has been looking at the problem of whether natural critical systems were possible. He notes that 1.4-billion years ago an optimum water-uranium mixture would have an infinite multiplication factor $k_\infty = 1.28$. If one "poisons" this with a proportionate amount of all the elements except the rare earths found in a typical uranium ore (Great Bear Lake pitchblende), k_∞ drops to 1.09. Since it would take only tiny factions of high-cross-section rare earths to drop k_∞ below 1, it seems highly unlikely that natural critical systems existed then.

However, 2.8-billion years ago k_∞ for the optimum water-U system was $\cong 1.6$. This gives much more margin for poisoning. Perhaps not unrelated is the fact that uranium minerals older than 2-billion years are always associated with considerable amounts of the rare-earth elements.

Computers Aid Radiotherapy Planning Dose distributions to be expected from proposed multiport or rotational radiation-treatment procedures can be computed quickly with the aid of punched-card computers. Such treatment procedures maximize the dose to a tumor while minimizing the dose to surrounding tissues. But the computation of dose distribution requires the summation of the dose received from each field. This is further complicated by the varying skin–tumor distance at the various irradiation angles.

At New York's Memorial Hospital, treatment planning involves the use of punched cards containing information based on dosimetric studies with phantoms. On the cards are listed the energy used (22.5, 1, 0.25 Mevp, or Co^{60}), the radiation-field size, the tumor–skin distance, and the angle between the beam and a reference line in the patient's body. In addition there is a main set of numbers giving the dose at points every 1 cm along a single radial line originating at the tumor site. A polar-coordinate system is used to locate points in the body of the subject and the orientation of the X-ray beam.

Sufficient accuracy is obtained by using angles spaced every 10 deg. Thus it takes 36 cards to specify the dose distribution in any one plane of the radiation field. In multiport treatment, one sums the distribution for each of the irradiation angles used. In the case of continuous rotational therapy, one can sum contributions from as many as 12 or even 36 angles.

Using the punched cards and a sorting machine it's a simple matter to select out those cards that correspond to each of the 36 radial lines used as fixed coordinates for the dose distribution in the body. Summing up the contributions point by point on a tabulating machine results in a readout giving the net dose distribution throughout the subject. This gives an accurate picture in advance and often suggests improvements. This technique was evolved by K. C. Tsien, *Department of Physics, Memorial Hospital.*

TWO INTERNATIONAL RESEARCH JOURNALS

Nuclear Energy

EDITORIAL BOARD

R. A. Charpie — *J. V. Dunworth*
J. Gueron — *D. J. Littler*
G. Randers

Commencing with volume 3 the journal is to be published in two parts under the same cover, Part II containing a verbatim translation of the new Soviet Journal of Atomic Energy (Atomnaya Energiya).

The contents of volume 3 No. 1, to be published in August, are as follows:

PART I

G. W. Greenwood and B. Sharpe: The effect of thermal gradients on metallic slurries.

R. Batchelor and H. R. McK. Hyder: The energy of delayed neutrons from fission.

H. J. M. Bowen: The determination of manganese in biological material by activation analysis, with a note on the Y-spectrum of blood.

N. J. Pattenden: The slow-neutron total cross-section of uranium-233

F. J. M. Farley: The yield of fission neutrons per neutron absorbed for Pu^{239} up to 60-eV incident energy.

C. P. Caillet and J. Carpentier: La dynamique de l'Empoisonnement d'un réacteur par le xénon.

R. P. Feynman, F. de Hoffmann and R. Serber: Dispersion of the neutron emission in U-235 fission.

PART II

Atomic Energy in the Service of Peace.

A. I. Alikhanov, V. V. Vladimirsky, P. A. Petrov & P. I. Khristenko: A heavy water power reactor with gas cooling.

D. I. Blokhintsev, N. A. Dollezhal & A. K. Krasin: The reactor at the atomic power station of the Soviet Academy of Sciences.

D. I. Blokhintsev, M. E. Minashin & Yu. Sergeev: Physical and thermal calculations for the reactor of the atomic power station of the USSR Academy of Sciences.

V. C. Emelyanov, P. D. Bystrov & A. I. Evstyukhin: An investigation of the iodide method of refining zirconium.

S. A. Baranov & K. N. Shlyagin: Energy levels of Pu^{239} and Pu^{240}.

G. F. Bogdanov, A. A. Kurashov, B. V. Rybakov & V. A. Sidorov: The measurement of fast-neutron spectra by time-of-flight methods.

V. G. Melkov: Methods of prospecting for uranium deposits.

D. E. Grodzensky: Isotopes in research on the pathogenesis of metabolic diseases.

Applied Radiation and Isotopes

EDITORIAL BOARD

P. C. Aebersold — *J. C. Bugher*
J. Coursaget — *V. N. Kondratiev*
M. Magat — *B. Manowitz*
H. R. Nelson — *J. L. Putman*
H. Seligman

The journal will provide a forum for the publication and discussion of the application of radioactive materials, and of effects of radiation on materials, e.g. food sterilization, the iniation and control of chemical changes etc.
The journal will also report on isotope methods and techniques of potentially wide application. It will publish news of general interest in the field.

CONTENTS OF VOLUME 1
Numbers 1 and 2

W. B. Mann: The preparation and maintenance of standards of radioactivity.

J. L. Putman and D. B. Smith: Radioactive tracer techniques for sand and silt movements under water.

John E. Lewis and Robert C. Plumb: Radiochemical technique for determining the specific surface area of aluminum metal surfaces.

F. Newton Hayes: Liquid scintillators: attributes and applications.

F. P. W. Winteringham: Labelled metabolic pools for studying quantitatively the biochemistry of toxic action.

R. M. Cambell, D. P. Cuthbertson, C. M. Matthews and A. S. McFarlane: Behaviour of ^{14}C- and ^{131}I-labelled plasma proteins in the rat.

G. B. Cook, J. Eakins and N. Veall: The production and clinical applications of ^{132}I.

F. J. Domingues, A. Sarko, and R. R. Baldwin: A simplified method for quantitation of autoradiography.

S. D. Gehman and I. Auerbach: Gamma-ray vulcanization of rubber.

R. Chauvin et P. Leveque: Utilisation d'un Discriminateur d'Impulsions Associé à un Détecteur γ à Scintillation pour l'Analyse par Activation.

Fully descriptive leaflets and sample copies of both journals available on request.

*SEE US AT BOOTH 432 IN CHICAGO

Pergamon Press

122 EAST 55TH STREET, NEW YORK 22, N.Y.• 4–5 FITZROY SQUARE, LONDON W1, ENGLAND

"SECRET" is about all we're allowed to say concerning many of the nearly half a hundred Air Force contracts now in various stages of design and development by Convair-Fort Worth's engineers and scientists. But it illustrates the advanced status of the projects facing us. Some of us are busy with the B-58, America's first supersonic bomber; others are exploring the feasibility of nuclear powered aircraft. The conception, the design, and the development required to achieve our goals present a staggering challenge that demands foresight and exploration into the unknown.

If you have a formal education or professional experience in any of the many fields of engineering and science needed to fulfill the broad and complex requirements of these projects of the future, you'll find a warm welcome and an unequalled opportunity to put your ability to its best use at Convair-Fort Worth. Here you'll work in an atmosphere of alert progress, with a wealth of highly advanced, specialized facilities to expedite the myriad phases of design and development now at hand, as well as those to come. Attractive job benefits, low cost-of-living, mild year 'round climate, adequate housing in all price ranges, limitless recreational facilities . . . all add up to ideal living conditions. Today—turn your thoughts to a better future for yourself *and* your family. Take time to investigate Convair-Fort Worth.

TODAY, investigate this opportunity to exercise your ability to your best advantage. Aircraft experience is NOT necessary. Address a resumé of your qualifications to:

Mr. H. A. BODLEY
Engineering Personnel, Technical Employment

Your inquiries are held in strict confidence

YOUR FUTURE IS ***NOW*** . . .
AT CONVAIR-FORT WORTH

CONVAIR
FORT WORTH

C-V FORT WORTH, TEXAS A DIVISION OF GENERAL DYNAMICS CORPORATION GD

APPLIED RADIATION

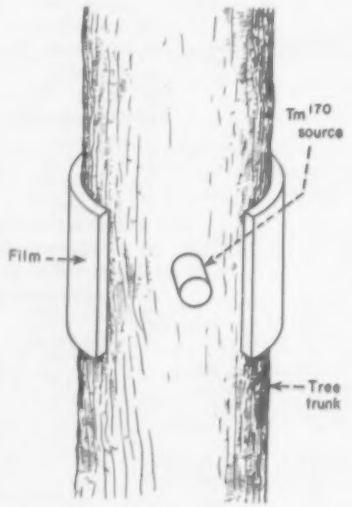
Expendable Food Dosimeter Needed

The Army's Quartermaster Research and Development Command has asked NUCLEONICS to publicize its need for an expendable dose indicator for foods. The indicator, to be used in the current food-irradiation program, should be "a simple, inexpensive device to indicate on a 'go' or 'no-go' basis whether a food package to which it is attached has received a specified dose. It should have a fairly sharp threshold and a response detectable by human senses without special instruments. Perhaps a tape, paint spot, piece of glass or plastic, or other object that changes color at a definite dose level could be used." Dose-level ranges run from 10–50 thousand rep to 1–10 megarep. The dosimeter should respond to electron beams at energies up to 30 Mev and dose rates to 5 Mrep/sec, to gamma fields of 0.2–3.0 Mev energy and dose rates to 10 Mrep/hr. Other desirable features would be, "freedom from loss of indication for weeks after irradiation, stability to temperatures from below freezing to 180° F, nontoxic nature, accuracy to something better than 50%, and easy, unequivocal detection of the change by nontechnicians." Have you any suggestions? Send them to NUCLEONICS, or write to G. E. Danald, Quartermaster Research and Development Command, 1819 W. Pershing Rd, Chicago 9, Illinois.

Tm^{170} Radiography Finds Tree Rot

With new "cross-fire" radiography, foresters of Iowa State College can inspect trees in a few minutes for decay caused by microorganisms. Milo Voss and G. Daly of the Institute for Atomic Research, Iowa State College, Ames, Iowa have developed the method in conjunction with foresters and botanists.

Plots of photographic-film density are substituted for photographs formerly made with an unwieldy X-ray machine and core samplings. As shown in the sketch, a thulium source weighing 20 lbs with its shielding is placed against the trunk of the tree; photographic film is wrapped around the other side.



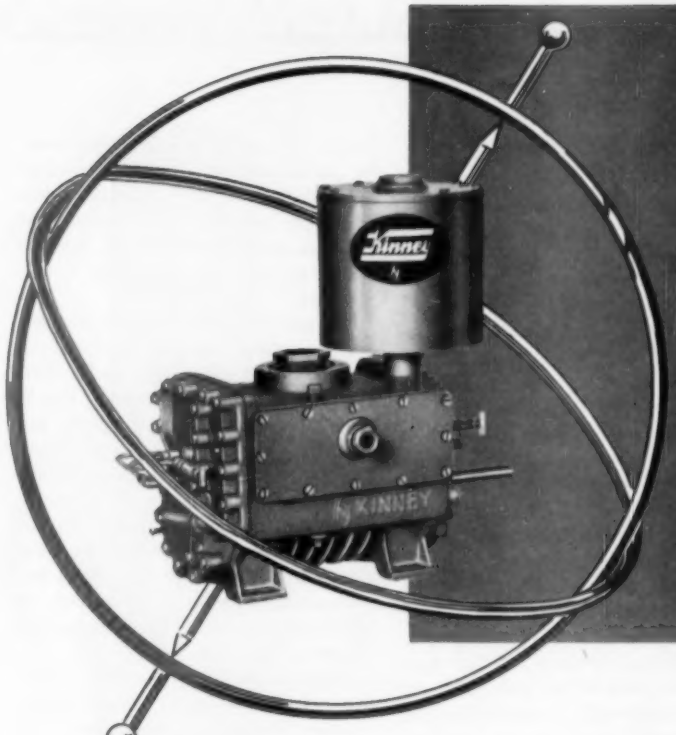
Irregularities in density of the developed film indicate abnormalities. A healthy tree produces a smooth variation along the film. Comparison of three exposures of the same cross section from different angles reveals the location and magnitude of the defect or infection.

Sensitivity is such that $\frac{3}{16}$-in. holes have been found in 9-in. logs. Most trees can be inspected in about 5 minutes. Attempts are now under way to study 36-in. trees with day-long exposures.

The botanists and foresters at Ames are using the method in their attempts to correlate tree diseases with growing conditions. The method is also applicable to inspection of such things as telephone poles and underwater pilings.

Surface Sterilization

Surface spoilage of fruits is a problem especially suitable for treatment with beta rays and accelerated electrons with energies up to 1 Mev, according to B. E. Proctor, head of MIT's Department of Food Technology. Shallow penetration with low-energy beta rays or accelerated electrons is sufficient to kill the microorganisms involved—molds and bacteria. The exact energy appropriate depends on the packaging material as well as the desired penetration. The same technique could apply to cut meats, packaged frankfurts, baked goods, and other products attacked by molds. Deleterious effects on flavor and texture would be minimal with the shallow surface treatment.



DYNAMICALLY BALANCED!

NEW Kinney®

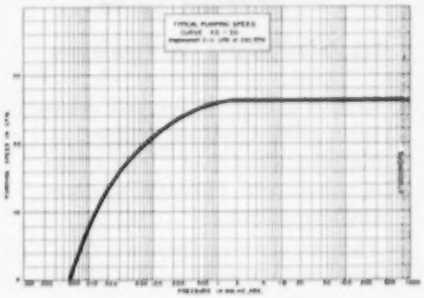
MODEL KD-30 HIGH VACUUM PUMP IS FUNCTIONALLY VIBRATION-FREE!

This Means...

- **A pump ideally suited for portable installations or for systems requiring a minimum vibration tolerance factor**
- **Increased wear-life of pump components**

This new, compact Model KD-30 pump of single stage-duplex design results from the continuing research and design experience that has made the Kinney vacuum pump line the world's largest. The "dynamically balanced" feature is vital in countless experimental, pilot plant, and production applications . . . and is augmented by other Kinney improvements, the Kinney Swirl Separator Tank, Gas Ballasting, etc. Check the specification data and pumping speed curve to see why Kinney is proud of this latest addition to its performance-proved line.

Our engineers will gladly send recommendations on your particular vacuum equipment needs. Request additional data today or contact one of our competently staffed district offices . . . in Baltimore, Charleston, W. Va., Charlotte, N. C., Chicago (La Grange), Cleveland, Detroit, Houston, Los Angeles, New Orleans, New York, Philadelphia, Pittsburgh, San Francisco, St. Louis . . . or The International Sales Office, 90 West St., New York 6, N. Y.



SPECIFICATION DATA

Model KD-30 Single Stage-Duplex Design High Vacuum Pump

Ultimate Pressure (McLeod Gauge)	10 Microns
Free Air Displacement	30.4 CFM
Free Air Displacement	14.4 Liters/sec.
RPM	525
Motor H.P.	1½
Motor RPM	1800
Oil Capacity	2½ qts.
Cooling	Air
Shaft Diameter	¾"
Inlet Connection	1½" screwed
Outlet Connection	1¼" screwed
Valve Type	Poppet
Separator Tank	Kinney Swirl
Net Weight, Complete Unit	370 lb.

Overall Dimensions, Complete Unit with Motor
Length — 28¾"; Width — 20⅛"; Height — 19⅞"

write today

KINNEY MFG. DIVISION
THE NEW YORK AIR BRAKE COMPANY
3614 WASHINGTON STREET • BOSTON 30 • MASS.
INTERNATIONAL SALES OFFICE, 90 WEST ST., NEW YORK 6, N.Y.

- Please send complete data describing the new Model KD-30 high vacuum pump.

Name ..... Title .....
Company .....
Street .....
City ..... State .....

65X RESISTORS

Values up to...

10,000,000 megohms

Here is a line of compact, high value molded resistors designed to meet the demands of a wide range of commercial, industrial and scientific applications.

Their excellent performance characteristics and wide range of values are ideally suited for atomic survey meters, radio and television service, scientific measuring devices, as well as many precision instruments.

They are subjected to an aging process in production to insure stability of resistance values in actual service.

Get full information on S.S.White 65X Resistors today. You will find they will meet and in many cases exceed the most stringent military requirements.

BULLETIN 5409
has full details. Send for a copy. Attention Dept. 9R.

S.S.WHITE INDUSTRIAL DIVISION
10 EAST 40th STREET • NEW YORK 16, N. Y.

Western Office:
1839 West Pico Blvd., Los Angeles 6, Calif.

BOOKS

Government Contracting in Atomic Energy

By RICHARD A. TYBOUT (University of Michigan Press, Ann Arbor, 1956, xiv + 226 pages, $4.50).

Reviewed by W. E. KELLEY, Walter Kidde Nuclear Laboratories, Inc., Garden City, N. Y.

The author has carried out a very painstaking study that, because of its thoroughness, cannot cover all the broad aspects of AEC contracting.

He calls attention to the AEC's method of doing business, with its government ownership of plants and contractor operation. The result of this method is the widespread use of cost-plus-fixed-fee contracts. The author sometimes appears preoccupied with social implications of this method of contracting, and thus loses the emphasis he might place on the fact that cost-plus-fixed-fee contracts are brought into being by hard and straight reasoning, as follows: (a) the AEC has a big job to do, usually on a tough schedule, (b) the job limits and risks are hard to define, (c) if contractors are directed to submit lump-sum bids, they must protect themselves with high bids, and (d) the AEC can save taxpayers money by taking the risk and uncertainty costs as and if they arise.

With a fixed fee, the contractor has no incentive to raise costs and he has the very real incentives of pride and reputation to carry out the work at minimum cost.

The facts are in this book, but I sometimes found them diluted with discussions and searches for other possible reasons.

The author's point that fees are payments in lieu of profits that the contractor's people might earn on other work is interesting, but I suspect some of the contractors would object. They might point out that with the same technical people, their earnings in industrial work would be far larger. My opinion would be that the fees are incidental to the benefits in technical growth, opportunity to train new people, and prestige in a new field.

A point that is not brought out in the analysis of the percentage of the AEC's appropriations spent through cost-plus-fixed-fee contracts is that much of this money is still spent at the contractor's level by competitive bidding—though carried in the "cost" category because it is spent by a cost-plus-fixed-fee prime contractor. This oversight in studies of the AEC's operations has been the source of much unfounded criticism and confusion. It appears that even the author's figures do not adequately emphasize this.

One penalty of the size of the detailed job the author attempted is that he had to limit himself largely to Hanford and Oak Ridge. The result of this is that little attention is given to the techniques of handling the many varieties of research and development contracts—the programs in basic sciences, medicine, and biology. In the long run, the AEC's policies in these things will have more long-range importance than the manner in which the billions were spent for hardware at Oak Ridge and Hanford.

Another book yet to be written should cover the AEC's contracting for reactors for research and power. In these things, as in many others, the AEC has had to pioneer in public service. These are largely recent developments subsequent to the present book's coverage.

I certainly agree with the general defense of the cost-plus-fixed-fee contract—most criticism of its use has been confused and biased by suspicion rather than fact. In my opinion, industry should be given more credit by all for pride in doing a good job and honesty in efforts to reduce program costs.

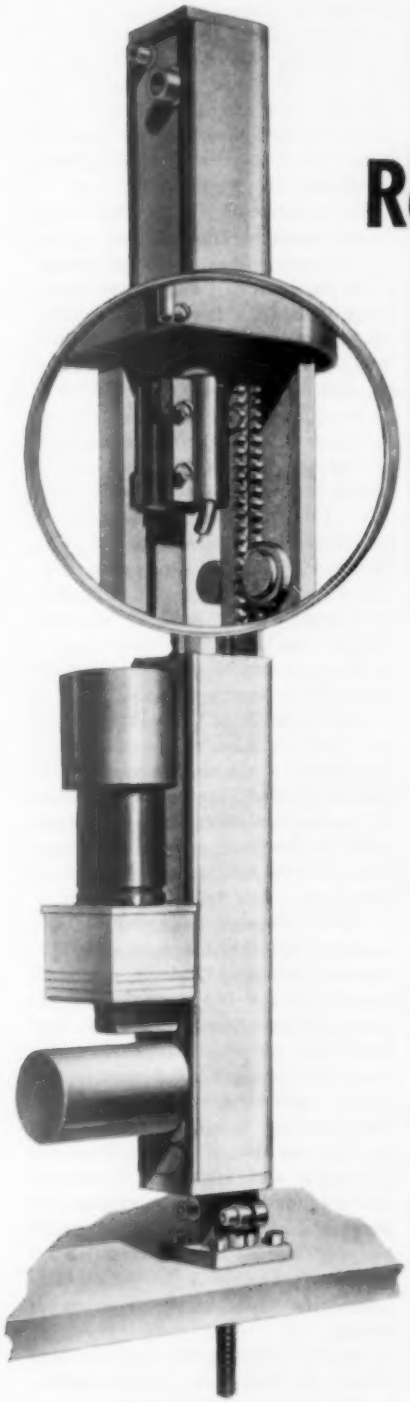
This book is for the student of government, and not for the businessman looking for a guide to contract negotiation and increased fees.

Geneva Volumes

Publication of the monumental United Nations series containing the proceedings of the Geneva Conference on the Peaceful Uses of Atomic Energy has been completed. The series probably forms the most complete and up-to-date storehouse of information on nuclear science that is available throughout the world today. Thirteen of the 16 volumes have already been reviewed here (NU, Feb. '56, p. 76; May, p. 118; Aug., p. 105).

Vol. 1—The World's Requirements for Energy: the Role of Nuclear Power. This volume contains the record of sessions that covered surveys of esti-

General Regulator Announces new



Reactor Shim Rod
and
Regulating Rod Actuators

OF UNUSUALLY rugged construction, the new GR electrically-operated actuators are designed both for accurate automatic positioning of regulating rods by means of electronic or contactor-type controllers and for accurate remote manual positioning of the shim rods.

Note these important advantages:

- A basic compact design and a special swivel bracket permit mounting actuators in adjacent spaces of the standard MTR grid.
- An interchangeable, high-speed, ball-bearing gear reducer is provided for obtaining various rack speeds.
- A one-stage worm-and-gear reducer prevents back driving or drift under load.
- Provision for using either potentiometers or synchros for position indication and control.
- Adjustable double-throw limit switches.
- Limit and intermediate position switches are so arranged that they are operated directly by the rack and are continuously adjustable over the entire stroke.

These new units are now undergoing life tests. At present, they have satisfactorily completed the equivalent of 5 years of normal reactor operation. They have been specified for Foster Wheeler Research Reactors and will be used on both the LPTR (Livermore Pool Type Reactor) and the DTTR (Danish Tank Type Reactor).

See this actuator in operation at the

FOSTER WHEELER EXHIBIT

Booths 405 and 406

1956 Trade Fair of The Atomic Industries

September 24-28 Navy Pier, Chicago

GENERAL GR REGULATOR

GENERAL REGULATOR CORPORATION

165 Broadway New York 6, N. Y.

A Foster Wheeler Corporation Subsidiary

Scientists . . . Engineers

. . . look to Westinghouse

Commercial Atomic Power

CAPA—Commercial Atomic Power Activity—is the nucleus of the most dynamic new division at Westinghouse, the leader in Atomic Power. Our growth is bound to be *steep*—as electric power demand and atomic power production pyramid sharply.

We're "fluid"—not fixed. New supervisory jobs open up fast! We're entirely *commercial*—not dependent on government contracts. Opportunities for advanced study at company expense. Get in on the "industry of tomorrow" *today* . . . at Westinghouse CAPA.

Immediate Openings for professionally established men and those just starting their careers: Physicists • Physical Chemists • Chemical Engineers • Mechanical Engineers • Electrical Engineers • Designers • Metallurgists.

Send your résumé

Please mail résumé of your professional and business background to: C. S. Southard, Westinghouse Commercial Atomic Power, Box 355, Dept. 146, Pittsburgh 30, Pennsylvania.

WATCH WESTINGHOUSE!

FIRST IN ATOMIC POWER

mated future power needs in the next five decades (session 2:1); individual countries' needs and possibilities for power and heat (2:2); capital investment required for nuclear energy (3:2); economics of nuclear power and the part played by plutonium and thorium (4); and the role of nuclear energy in the next 50 years (5). Also in this volume is the record of the session on international cooperation in peaceful uses of atomic energy, including work in education and training.

Here, obviously, is to be found the fundamental background and setting for nuclear energy, its basic *raison d'être* in terms of the harsh economic facts of life; also the raw material for attempting estimates, at least in relative terms, of the order in which various regions of the world will find nuclear power becoming competitive.

Session 2:2 was one of the moments during the Geneva Conference when the underdeveloped countries had their say. Here are the statements of 33 countries—including Burma, Thailand, Korea, Pakistan, Ceylon, Jordan, Iran, Syria, Brazil, Uruguay—outlining their power needs, and what they hope and expect from the atom.

On the economic side are down-to-earth discussions by such authorities as W. K. Davis, J. A. Lane, Philip Sporn and Walker Cisler, among others, and an account of the oft-discussed British plutonium credit system. The papers on nuclear education should be of great value in this field, especially to those charged with setting up new training programs.

Vol. 5—Physics of Reactor Design. Included here are the papers and discussions related to integral measurements (Session 19A); resonance integrals, fission-product poisoning, and criticality of solutions (20A); zero-energy and exponential experiments (21A); zero-energy experiments on fast reactors, reactor kinetics (22A); and reactor theory (23A). These experiments and analytical treatments are of fundamental importance in establishing the basic nuclear design for any reactor configuration. They permit establishment of design specifications on which to base engineering design.

Session 19A describes how neutrons diffuse in beryllium, BeO, graphite, water, and other hydrogenous media, and in various shapes. Pulsed neutron sources, subcritical assemblies, and time-of-flight spectrometry are among the experimental tools used.

Session 20A contains papers on a

variety of methods for analyzing and measuring neutron absorption in the resonance-peak zones of the cross-section curves. Also included are papers describing the buildup of fission-product poisons in thermal and natural uranium reactors, and papers on homogeneous and plutonium-water critical assemblies.

Zero-energy and exponential experiments are described in the papers of Session 21A. Graphite, H_2O, and D_2O were used as moderators in heterogeneous systems using natural uranium. Some experimenters used slightly enriched uranium; the PWR critical experiments also are described.

Experiments with the British fast assemblies Zephyr and Zeus were described in Session 22A. Other papers in this session touched on theoretical and experimental aspects of fast reactors, reactor kinetics, testing control-rod theory, and neutron instrumentation for reactors.

Session 23A has 21 papers covering many aspects of the theoretical approach to reactor nuclear design.

Vol. 13—Legal, Administrative, Health and Safety Aspects. As indicated by the title, this volume ranges over a wide field. Session 4:3 of the conference covered legal and administrative problems, such as insurance, workmen's compensation, boiler safety codes, isotope regulations, industrial training, and the organization of a national semi-governmental atomic energy company. Session 6:2 covered reactor safety and site selection; it includes a paper on safety by C. R. McCullough, chairman of the U. S. Advisory Committee on Reactor Safeguards; the account of the Borax-1 supercriticality experiments leading to its destruction, and discussions of radiation from clouds of reactor debris, and of monitoring of a nuclear release. Safety standards and maximum permissible exposure levels were discussed in session 17C; hazards related to uranium mining in 17C:2; and hazards related to reactor operation and chemical processing in 18C:1. Finally, under session 18C:2 on ecological problems may be found discussions of a variety of environmental aspects, including the relationships of atomic energy to meteorology, to biological cycles, to oceanography, and to plants and animals near reactor sites.

Like all the other Geneva volumes, this one is liberally sprinkled with illustrative charts, tables and bibliographical references.

INSTRUMENTATION FOR *Nuclear Research*

Developers of special purpose instruments made to customer requirements

Manufacturers of Scala-O-Matic counting circuits, Geiger counter tubes, scintillation counters, civilian defense instruments, chemical dosimeters, absorber sets, portable radiation detectors, and lead shields.

Improved JUNO

A portable, lightweight, battery-operated instrument, which measures the intensity of, and distinguishes between alpha, beta, and gamma radiation.

CUTIE PIE

A self-contained battery-operated air ionization chamber instrument for use in probing for beta and gamma radiation. Provided with shield for rejecting beta particles.

LEAD SHIELDS AND ACCESSORIES

LS-1 General purpose shield for use with thin-wall counter tubes.

LS-4 Useful in determining the radioactivity of liquids and pulverized solids.

LS-6 Largest and heaviest standard shield produced by Technical Associates.

Hand and Foot RADIATION MONITOR

This counting rate instrument indicates alpha, beta and gamma contamination of back and palm of each hand, and beta and gamma contamination of the soles of both feet.

Write for Bulletins

TECHNICAL ASSOCIATES

140 West Providencia Avenue • Burbank, California

Wanted:

by the industry's leading technical literature specialists

MANUALS

of the most superior quality

TO PRODUCE

most quickly and economically

The professional organization producing the greatest volume of technical literature in the electronics field is now available to you. We have complete facilities for organizing, writing and illustrating your operating and maintenance manuals for equipment—or any technical literature you may require—at substantial savings in time and money. Complete production and printing facilities are a part of our integrated operation. Your inquiries are cordially invited.

call or write **HOWARD W. SAMS & CO., INC.**

Special Services Division, 2201 E. 46th St., Indianapolis 5 • Phone: Glendale 4531

Ask for it

We'd like to send you our brochure: "The Story of a Unique Service"

Analyze
URANIUM
in any form
in concentrations of 0.001% and less

JAco G-M
Fluorimeter

Whether your problem is in research, production control, or ore assaying, you can make faster, more accurate analyses of uranium with the JAco G-M Fluorimeter. Leading mines, mills, metallurgical plants and laboratories all over the world report making 50 to 100 determinations a day — even when sample concentrations are 0.001% or lower.

The JAco G-M Fluorimeter offers you the high precision sensitivity and stability you want, because its advanced design includes exclusive features:

No Cooling System — Blacklight Blue lamps used as ultraviolet source require no cooling.

No Optical System — sample slide, light source and detecting system are mounted in close proximity eliminating optics and allowing low voltage across dynode of the photomultiplier tube.

Improved Power Source — circuit compensates for input-output voltage and tends to compensate for heater voltage variation.

Convenient Control Grouping — handy keyboard arrangement of switches and controls cuts time, reduces fatigue.

Discover all the ways this outstanding JAco instrument can help you to do your job better. Write today for descriptive bulletin.

JAco JARRELL-ASH COMPANY
26 Farwell Street, Newtonville, Mass.

SALES OFFICES: ATLANTA, GA. CHICAGO, ILL. LOS ANGELES (Duarte) MUSKEGON, MICH. PITTSBURGH, PA. NEW YORK, N.Y. PALO ALTO, CAL.

ALSO OF NOTE

Ingegneria Nucleare, by Francesco Mazzoleni (Ulrico Hoepli, Milano, 1956, x + 470 pages, 4,000 lire). This textbook on nuclear engineering must surely be welcome in Italy, now striving to catch up in a field that one of her emigrant sons did so much to launch. The book covers the structure of matter; nuclear reactions; neutron scattering and moderation; nuclear reactors; principles of theory and of construction; fissionable, moderating and control elements; applications of nuclear energy. The author, a member of the faculty of special technologies at the University of Naples, seems intimately familiar with the American literature as well as with the English and German; he presents his material clearly and attractively, and 140 lucid illustrations should be most helpful to the student.

Symposium on Structure of Enzymes and Proteins. The symposium was sponsored by the Oak Ridge National Laboratory Biology Div., in Gatlinburg, Tenn., April '55, as the Eighth Annual Biology Research Conference. Included are the symposium papers and a roundtable discussion of nucleoproteins. A limited number of copies are available free to scientific investigators who can establish their need for the publication. *Biology Div., Oak Ridge National Laboratory, P. O. Box Y, Oak Ridge, Tenn.*

Digital Differential Analyzers, by George Forbes. Intending this as an applications manual, the author emphasizes the mathematical capabilities and limitations of the equipment and preparation of a schematic to represent the given problem adequately. *George F. Forbes, 10117 Bartee Ave., Pacoima, Calif., $7.50.*

Bulletin of the Academy of Sciences of the U. S. S. R. Physical Series. Complete English translations are available, offset printed, starting with No. 3 of vol. 18 (1954). The subscription rate is $110 per year; single issues are $20. Tables of contents are free on request. *Columbia Technical Translations, 5 Vermont Ave., White Plains, N. Y.*

Testing Mass Standards by Substitution. This 16-mm color and sound film is produced by the National Bureau of Standards. It is designed as a training aid and runs 22 min. *Office of Technical Information, National Bureau of Standards, Washington 25, D. C., for loan or sale.*

Hydraulic Research in the United States. NBS Miscellaneous Publication 218, by Helen Middleton, is compiled from hydraulic and hydrologic laboratory reports of the U. S. and Canada. Projects are listed chronologically. *Government Printing Office, Washington 25, D. C., $1.50.*

BNL Research Reactor Facility Irradiation Services and Radioisotopes. This booklet is available to users and prospective users of Brookhaven National Laboratory reactor services. It describes the reactor and facilities and the various services (reactor, γ-ray irradiation, hot laboratory, biology irradiation, and cyclotron). Also included are instructions on orders, shipping information and charges, and price schedule. *Brookhaven National Laboratory, Associated Universities, Inc., Upton, N. Y.*

Units and Systems of Weights and Measures. Circular 570 of the National Bureau of Standards brings together information on customary and metric systems of weights and measures. *Government Printing Office, Washington 25, D. C., $0.25.*

BOOKS RECEIVED

Medical Effects of the Atomic Bomb in Japan, National Nuclear Energy Series VIII-8, edited by Ashley W. Oughterson and Shields Warren (McGraw-Hill Book Co., Inc., New York, 1956, xvi + 477 pages, $8.00). *(To be reviewed.)*

Abacs or Nomograms, by A. Giet (Philosophical Library, Inc., New York, 1956, xi + 225 pages, $12.00). Translated from the French by J. W. Head and H. D. Phippen, this book is intended for practical engineers rather than mathematicians. Many applications of nomograms are discussed as well as how to construct them without having highly specialized mathematical knowledge. In many cases the French units of the original book have been converted to English units.

Sodium—Its Manufacture, Properties, and Uses, by Marshall Sittig (Reinhold Publishing Corp., New York, 1956, viii + 529 pages, $12.50). This book, American Chemical Society monograph 133, for the first time provides a key to the vast literature on sodium. Its chapters cover manufacture, solubility and alloys, handling techniques, uses, inorganic and organic reactions, analytical chemistry, and physical and thermodynamic properties.

RAY PROOF

radiation shielding

Lead Shields	Lead Doors and Operators	Lead Louvers
Lead Laminations	Lead and Concrete Blocks	Lead Bolts
Lead Containers	Lead Observation Ports	Fume Hoods
Lead Castings	Special Designs	Viewers

RAY PROOF CORPORATION—*pioneers in the creative use of structural materials for shielding*—invites you to the utilization of our services.

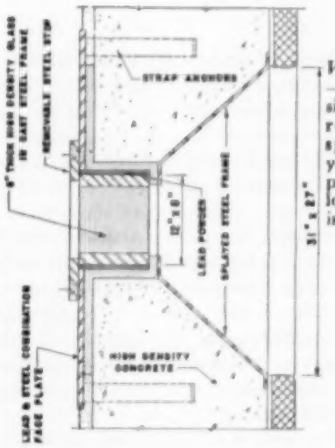
A scientific study of your shielding problems combined with practical construction knowledge is essential to your interests.

We offer you—

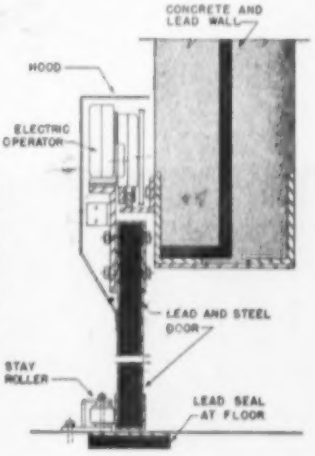
- Over 27 years experience in radiation shielding *exclusively.*
- Over 40 years experience in design, construction and manufacturing.
- Services of the oldest *exclusive* shielding company in America.
- Services of engineers, physicists, and construction specialists.

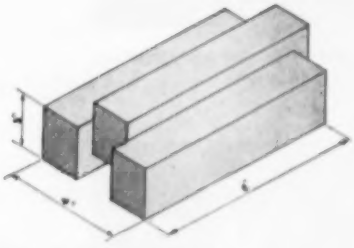
Join the many outstanding names in American industry whom we have served. A list sent on request.

Shielded Doors—lead—steel—wood or in combination of materials. Standard or specially designed. Manual or fully mechanized—*but always safe.*



Viewing Windows—A variety of designs—to meet the required density specifications of your installation. A practical unit for low cost application is our prime effort.





RAY PROOF Safety Bricks, lead or high density concrete—containers—safes and many other devices—all designed for safety—practical application and low cost consideration.

Apply for details and quotations—

"RAY PROOF often imitated but never equaled."

RAY PROOF CORPORATION

513 West 54th Street, New York 19, N. Y.

Telephone: PLaza 7-0810

Navy Pier at Chicago is the scene of 1956 Trade Fair to be sponsored by Atomic Industrial Forum from September 24 to September 28

Second Atomic Trade Fair

Mockup of shippable power reactor. Glenn L. Martin Co.

Pressurized-water reactor, steam generator. Babcock and Wilcox

An audience of more than 15,000 is anticipated for the 1956 Trade Fair of the Atomic Industry to be held September 24–28 at Navy Pier, Chicago, Ill. Sponsored by the Atomic Industrial Forum, the fair will display a wide range of products and services for the nuclear industry.

The first Trade Fair of the Atomic Industry was held in Washington, D. C., last September. This year's event will be larger and will have exhibits from more firms. Last year's show drew an audience from 44 states and 41 foreign countries. An equally representative foreign contingent is expected this year.

Highlighting the '56 fair will be displays from virtually every major reactor builder in the country, a substantial number of new, simulated-motion reactor models, reactor simulators, control equipment, and a wide range of reactor components and equipment for the field. Other subjects will be materials on research, development, and consulting services, and technical publications. Some exhibitors will provide continuous film and slide showings and special product demonstrations.

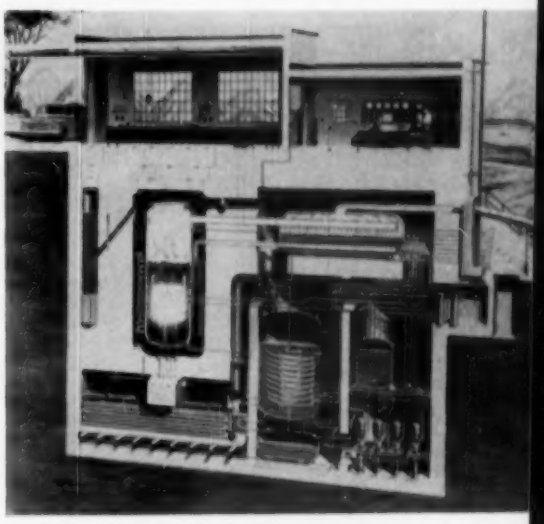
A special event associated with the fair will be a morning session on Thursday, September 27, at the pier on careers in nuclear science. It is intended for an audience of 1,500 selected high school students from Chicago and nearby. Another will be a limited series of guided tours of the new research-reactor facility at the Armour Research Foundation in Chicago. These will start from Navy Pier and go by special bus to the foundation on a schedule.

The week of the fair will also see the major Atomic Industrial Forum conference of the year at the Morrison Hotel near the pier. Theme of the meeting will be "Management and Technology for the Atomic Industry." Its dates are September 25–27. During the meeting special buses will run from the hotel to the pier.

Admission to the conference sessions will be by registration fee, but there is no charge for qualified observers at the fair. A complimentary ticket to the fair was bound into the August issue of NUCLEONICS. Data on the 3-day meeting and extra tickets for the fair can be obtained by writing on business letterhead to the Atomic Industrial Forum, 3 East 54th Street, New York 22, N. Y.

The following is a list of the exhibitors at the fair and the subjects of their exhibits. Booth numbers are in parentheses after each of the descriptions.

Single-region aqueous homogeneous power reactor. Foster Wheeler Company



Closed-cycle boiling-water reactor with associated heat exchanger and steam generating equipment. AMF Atomics

Ready to Open at Chicago

ACF Industries, Inc., Nuclear Products Division, New York, N. Y. Complete engineering, design and manufacturing services for nuclear facilities, reactors of all types and reactor components for both industry and government. Presently ACF is constructing three research reactors: 1–5-Mw CP5 heavy-water type for MIT and for the Italian National Committee on Nuclear Research and a 20-Mw ORR light-water type for Netherlands Reactor Center. (*253, 254, 353, 354*)

ALCO Products, Inc., Schenectady, N. Y. Nuclear reactors and generating plants, pressure vessels, heat exchangers of all types, and control-rod drive mechanisms. Army Package Power Reactor, prototype pressurized-water type reactor plant being built at Fort Belvoir, Va., under contract with AEC. Critical facility at Schenectady, N. Y. (*410, 411*)

Allied Resinous Products, Inc., Conneaut, O. Polyethylene sheets, rods, blocks, tubes, and large castings. (*442*)

Allis-Chalmers Mfg. Co., Milwaukee, Wis. Pumps for nuclear power applications including hermetically sealed, reverse-flow-Einstein, linear, and "Electri-Cand" units. Photos of a liquid metal pump for handling high-temperature sodium (Type EBR-2) and a main circulating pump for a pressurized water reactor. (*134, 135*)

American Laundry Machinery Co., Cincinnati, O. Complete line of special laundry equipment manufactured for decontamination of radioactive protective clothing worn by personnel engaged in nuclear fuel production, chemical processing laboratories, and reactor operations. Survey and engineering services. (*341*)

American Nuclear Society, Oak Ridge, Tenn. World-wide society for the nuclear engineer and scientist; publisher of *Nuclear Science and Engineering*, bi-monthly technical review. W. W. Grigorieff, executive secretary. (*454*)

American Radiator and Standard Sanitary Corp., Redwood City, Cal. Nuclear reactors for power and research; consulting services on reactor engineering, physics, metallurgy, and instrumentation; atomic equipment. (*126, 127*)

American Turbine Corporation, Licensors for Escher Wyss, Ltd., New York, N. Y. Closed-cycle gas turbines for nuclear power. Scale model of a 20,000-SHP nuclear ship-propulsion plant, a working model of a reversible turbine of the radial-inflow type. A

Session Subjects of AIF's annual conference on management, economics, and technology for the atomic industry, Morrison Hotel, Sept. 25–27

Tuesday, Sept. 25, 9:30—*Concurrent sessions on: economics of power-reactor systems; impact of atomic energy on the law; radiation utilization.*
2:30—*Concurrent sessions: new power-reactor developments; impact of atomic energy on the law (cont.); radiation utilization (cont.)*
Wednesday, Sept. 26, 9:30—*Concurrent sessions: elements of nuclear-power costs; the insurance problem; research programs and facilities.*
2:30—*Concurrent sessions: reactor materials; the businessman looks at atomic energy; information requirements of the atomic industry.*
Thursday, Sept. 27, 9:30—*Concurrent sessions: new reactor projects; power-demonstration program; international developments; impact on other fields.*

C-A-C®

MAGNETIC AMPLIFIERS & TRANSFORMERS

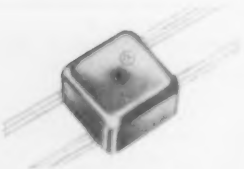
MAGNETIC AMPLIFIERS. Custom computer amplifiers with high stability and linearity can be designed having single or multiple inputs to your specific needs. Servo drives and relay actuators are also available. Frequency selective networks can be integrally designed to provide additional useful control functions. Proven packaging techniques insure minimum size—proven toroidal construction assures highest performance.

Typical Temperatures.. – 60° C. to +150° C.
Typical Line Frequencies ..... 60cps to 6000cps

MISSILE POWER TRANSFORMERS. Recommended for supply frequencies above 400 cps and where size performance and reliability are factors. Thin nickel alloy toroidal cores reduce core losses. Toroid structure cures stray field problems.

SEALED MISSILE POWER SUPPLIES combining toroidal power transformers, toroidal filter chokes, hi temp capacitors and silicon rectifiers. These units offer multiple outputs and low ripple. Low stray field of toroidal elements obviate usual internal shielding. Mag regulation where required.

LAMINATED TRANSFORMERS AND INDUCTORS. A complete line of laminated constructed units are now available through CAC. Our highly qaulified engineering staff, a well complemented laboratory, humidity controlled production facility with modern manufacturing equipment guarantees conformance with any specifications. Both power and audio transformers employing advanced techniques can be supplied either hermetically sealed or encapsulated to 150° C. ambients. Catalogs, supplied upon request, cover a wide range of standardized designs including omnirange and ILS Filters.



PRECISION RATIO COMPUTER TRANSFORMERS. Toroidal form of construction is ideal for designing precision ratio transformers since the turns of wire are applied to and adjusted on the core. Normal production procedure of zero turn accuracy, high permeability cores, low phase shift, and near unity coupling will yield laboratory quality on any production run. Advanced design and newest packaging methods provide optimum performance with minimum size and rugged construction.

Catalogs on Individual Components are Available on Request

COMMUNICATION ACCESSORIES CO.
World's Largest Exclusive Producer of Toroidal Windings
HICKMAN MILLS, MISSOURI • PHONE KANSAS CITY, SOUTH 1-6111
A Subsidiary of Collins Radio Company

Nearly completed building for Army Package Power Reactor at Fort Belvoir, Va. ALCO Products, Inc.

scale model of a small, closed-cycle plant for test purposes. (*107, 108*)

AMF Atomics, New York, N. Y. Master-slave manipulator for radioactive materials handling. Scale model of swimming-pool research reactor. Shadow-box depiction of closed-cycle boiling-water power reactor. Operating control-rod drive. (*407–409*)

Anton Electronic Laboratories, Brooklyn, N. Y. Area-survey trailer and mobile radiological laboratory, nuclear tubes and instruments, specialized components. (*100*)

Applied Radiation Corp., Walnut Creek, Cal. Linear electron accelerators and other particle accelerators and components for production of high-energy electron, X-ray, and neutron fluxes. Contract radiation facility in Walnut Creek, Cal., with beam energies up to 12 Mev. (*251*)

Argonne National Laboratory, Lemont, Ill. Visual report on most recent developments, principally in reactor technology and allied fields, within classification limits. (*443–445*)

Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill. Registration center for controlled-attendance tours of ARF industrial nuclear research reactor. At the reactor site, there will be charts and sketches of parts and operation of the reactor and guides to explain the reactor. (*148*)

Atnu Engineering Co., Hinsdale, Ill. General engineering and management services; research and development consulting services in theoretical and applied nuclear energy problems, including reactor analysis and design, fuel-element development, radiation effects on materials, fuel-element processing, radioactive-waste processing, irradiation facilities, feasibility and technical studies. (*433*)

Atomic Development Mutual Fund, Washington, D. C. Shares in Atomic

Development Mutual Fund, Inc.—a package of nearly 100 companies active in all phases of atomic energy: mining, ore-processing, refining, fuel fabrication, reactor manufacture, and application of atomic energy in research, electric-power production, and military propulsion. *(103)*

Atomic Energy of Canada, Ltd., Ottawa, Ont., Canada. Kilocurie Co^{60} sources and equipment for research, industrial processing, and radiotherapy; reactor-produced radioisotopes of high specific activity; radiography sources; a new radiography camera having a capacity of 750 c of Co^{60} for heavy radiography; neutron, alpha, and beta sources; design, consulting, and manufacturing services relating to applications of radioisotopes. *(207, 208)*

Atomic Industrial Forum, Inc., New York, N. Y. Theme display and reception-information center; display to outline scope of the atomic industry and the role of Forum activities and services in aiding the development of that industry. *(200, 201, 300, 301)*

Information center for details of AIF membership, publications, Memo, 1957 Trade Fair. *(456, 457)*

Atomics International, Division of North American Aviation, Canoga Park, Cal. Scale models of nuclear reactors; models of power and research reactors that the company has designed and built, or is building. The Sodium Reactor Experiment, an experimental reactor that is part of the AEC's program to develop economical power from atomic energy. *(228, 229, 328, 329)*

Babcock & Wilcox Co., New York, N. Y. Advanced nuclear reactors for research and complete nuclear steam-generating plants for production of electricity or process steam. Nuclear fuel elements, pressure vessels, heat exchangers and other components, and critical test services. Moving model of pressurized-water power reactor, fuel elements. *(218, 219, 318, 319)*

Baird Associates-Atomic Instrument Co., Cambridge, Mass. Scalers for G-M, scintillation, or proportional counting; nonoverloading linear amplifier; single-channel differential scintillation spectrometer, a complete system for qualitative and quantitative analysis of the energy spectra of gamma-emitting isotopes; bench-type lead-shielded scintillation counter; scintillation probe for laboratory, medical, and industrial use; collimator with cart and arm. *(137)*

Battelle Memorial Institute, Columbus, O. Facilities, equipment, and

IS THIS THE INSTRUMENT YOU'RE LOOKING FOR?

Victoreen MODEL 640

LOW ENERGY RADIATION SURVEY METER

This new Model 640 Victoreen Radiation survey meter was developed to locate and measure the unknown health hazards emanating from the operation of industrial and medical high voltage equipment. With this instrument low energy and low intensity x-rays generated from magnetrons, hydrogen thyratrons, betatron magnets and other high voltage equipment can be measured at tolerance level intensities of as little as 6 mr/hr. It will also provide measurements in the presence of intense radio frequency fields. It can be used to check TV sets (both on the production line and in laboratory experiments) x-ray machines such as fluroscopes, shoe fitting machines and spectrometers. Other high voltage vacuum tube equipment such as diathermy machines, radio and TV transmitters and radar that generate health hazard rays can be definitely measured with the 640 survey meter.

THESE FEATURES ARE IMPORTANT

Two energy ranges are provided, 8-50 Kev with mylar window only and 50-2000 Kev with bottom cover plate in place. Can also be supplied with beryllium window if desired. Accuracy is ±10%. Readings in each range can be made within 2 seconds.

Three sensitivity ranges, 10; 100; 1000 mr/hr. are available and may be selected by external range switch. Instantaneous zero adjustment can be made by convenient external control. Coarse zero adjustment and meter calibration controls are inside instrument case to prevent erroneous adjustment.

The 640 survey meter is compact and weighs less than 5 lbs. The attractive, aluminum case contains all components, including power supply consisting of a mercury cell and eight 22½ volt batteries which will provide well over 100 hours of operating life. A 100% negative feedback circuit eliminates the effects of differences in the tubes and components.

For detailed specifications write for Bulletin 3044.

The Victoreen Instrument Co.

3802 Perkins Ave. • Cleveland, Ohio

NUCLEAR CHALLENGE

There are still a lot of problems to be solved in the design of any reactor. But the difficulties are multiplied many fold when it comes to developing a practical nuclear aircraft engine. Shielding, weight limitations, other factors make it one of the toughest engineering problems of today.

Are you the type of engineer who wants a challenge to his mental abilities? Are you looking for an opportunity to do original, creative thinking on an outstanding engineering team where new ideas are encouraged? Then we may have an interesting, profitable future for you here, particularly if you are an . . .

AERONAUTICAL ENGINEER
CHEMICAL ENGINEER
MECHANICAL ENGINEER
ENGINEERING PHYSICIST
METALLURGIST

A few of the many personal benefits . . .

- **New higher salary levels**
- **Association with engineers and scientists of recognized ability**
- **Nearby R.P.I. graduate school for advanced study**
- **Suburban living in central Connecticut**
- **The prestige of an internationally known growth corporation**

* * *

Please send your resume to Mr. P. R. Smith, Office 13, Employment Department

PRATT & WHITNEY AIRCRAFT

DIVISION OF UNITED AIRCRAFT CORPORATION, EAST HARTFORD 8, CONNECTICUT

World's foremost designer and builder of aircraft engines . . . .

technical manpower for research and development in all fields of science, including research reactor producing fast and thermal neutrons and gamma flux, critical-assembly laboratory, hot cell, special area for processing enriched uranium, complete fuel-element and reactor-materials-development laboratories. *(330)*

Beryllium Corp., Reading, Pa. Nuclear-grade beryllium oxide shapes; nuclear-grade beryllium metal, including rods, electrolytic flake in powder and compacts; zirconium shapes including tubing, rod, strip, and extrusion; reactor core of uranium oxide and beryllium oxide. *(415, 416)*

Modular laboratory equipment made of stainless steel includes biological incubators and refrigerators, microscope recessed panel, and glove boxes. S. Blickman, Inc.

S. Blickman, Inc., Weehawken, N. J. Microbiological safety cabinet including filter for safe handling of biological contaminants and radioactive materials; information on modular biological laboratory equipment—basic enclosure and additional components including incubator, refrigerator, filter cannister, U V air lock, microscope recessed panel, centrifuge well, liquid pass tank, centrifuge, autoclave, cabinets; information on light plate-alloy-sheet fabrication. *(210, 211)*

Borg-Warner Corp., Chicago, Ill. Byron Jackson Division, Los Angeles, Cal. Pumping equipment for nuclear reactors. *(311)*

Detectolab, Chicago, Ill. Radioisotopes, tracer-detecting equipment, spectrometers, amplifiers, and analyzers. *(242, 243)*

Marvel-Schebler Products Division, Decatur, Ill. Fully remote electromechanical manipulator, for use in hot laboratories and remote assembly and maintenance operations. Electromechanical-hydraulic equipment. Nuclear research. *(242, 243)*

Brush Beryllium Co., Cleveland, O. Beryllium metal and beryllium products. *(449)*

Budd Company, Nuclear Systems Division, Philadelphia, Pa. Gamma-radiography sources and equipment. High-intensity gamma sources for industrial research. Irradiation and consultation services. New Radiation facility. *(417, 418)*

Bureau of National Affairs, Inc., Washington, D. C. Atomic Industry Reporter, a three-binder, weekly loose-leaf service on the entire atomic industry. *(145)*

Callery Chemical Co., Callery, Pa. Electromagnetic pumps, flowmeters and pressure gauges for high-temperature heat-transfer systems; also alkali-metal-purification systems. Company produces NaK, used as a heat-transfer fluid, and designs, builds liquid-metal heat-transfer systems. *(452, 453)*

Carborundum Metals Co., Niagara Falls, N. Y. Reactor-grade zirconium metal and alloys in sponge, ingot and fabricated shapes. *(230, 231)*

Carpenter Steel Co., Union, N. J. Stainless steel and high alloys of steel in tubing and pipe forms, plastic pipe, and nondestructive testing for inspection of this material. *(338, 339)*

Central Research Laboratories, Red Wing, Minn. Complete operating pairs of three different models of master-slave manipulators incorporating latest improvements. A wide variety of manipulator accessories such as protective booting, special-purpose interchangeable tongs, load hooks, motion locks, and remotely operated cranes for hot-cells. *(246, 346)*

Chatham Electronics, Division of Gera Corp., Livingston, N. J. Survey meters and dosimeters used for personnel protection wherever radioactivity or X-ray hazards exist. Specialized radiological instrumentation for atomic energy installations and research in the field. *(153)*

Chemical Fund, Inc., New York, N. Y. $134-million mutual fund providing investors with a method of participating in the growth of chemical industry. Portfolio of over 50 chemical securities supervised by F. Eberstadt & Co., aided by its chemical consultant, Arthur D. Little, Inc., of Cambridge, Mass. *(206)*

Combustion Engineering, Inc., New York, N. Y. Moving and pictorial displays of nuclear work and facilities

University of Michigan laboratory technicians handle a low-level radioactive sample in the "hot storage" area. The standard Corning shield is 36 inches thick. Corning will also build any custom shield you want.

The radiation window that gives you a view as clear as this costs the least

If you were actually standing outside the University of Michigan's radiation cave number 2—instead of looking at a screened reproduction of a photograph—you'd be able to see clearly any small detail you wanted to.

Anything you could read with your naked eye you could just as easily read through this yard-thick, almost water-white Corning Radiation Shielding Window.

It's made of 3.27 density Corning Code 8362 lead glass that inch-for-inch matches dense concrete for shielding. Nonbrowning Code 8362 doesn't lose transparency with time.

You need no fluid shielding medium with the Corning window. There's nothing to replace or recondition. It comes as a "package"—ready for insertion in your cell wall.

Nonbrowning, nondiminishing shielding, resistance to abrasion plus the most shielding per dollar of any window, all make Corning Code 8362 the most economical shield you can buy.

BRIEF SPECIFICATIONS

Code 8362 has a refractive index of 1.594 and an internal transmittance of 93% in 5" thickness with sodium lighting. It's chemically stable, indifferent to moisture, and optically clear.

It's cerium stabilized, resists browning and recovers rapidly from tinting. You can order single-piece thicknesses to 12" and sizes up to 100" x 70". We'll make the window you need to your specifications.

For detailed information, write to us.

FOR LEAD AND STEEL WALLS

Corning Code 8363, a 6.2 density glass, meets the requirements of lead and steel walls, or backs up Corning Code 8362 in 300 lbs. per cu. ft. concrete walls. Combinations of Corning Shielding Glasses have been installed in windows with a total glass path of over 200 density inches.

Write for Technical Bulletin No. PE-50, "Radiation Shielding Glasses by Corning." It covers properties and characteristics.

SEE THESE WINDOWS at our exhibit. The Trade Fair of the Atomic Industry Sept. 24-28, 1956, Navy Pier, Chicago, Ill.

Technical Products Division

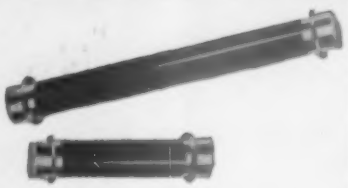
CORNING GLASS WORKS

16-9 CRYSTAL STREET, CORNING, N. Y.

Corning means research in Glass

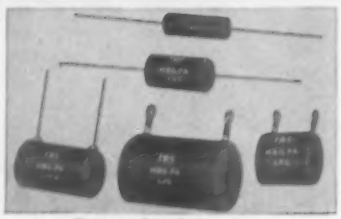
RESISTORS

HIGH VOLTAGE • HIGH MEGOHM • HIGH FREQUENCY



Wire Wound Precision Meter Multiplier Resistors

Type MFA and MFB High Voltage Wire Wound Resistors are Hermetically Sealed in glazed steatite tubes with ferrule ends for maximum protection against all adverse environmental conditions. Fully meet all requirements of JAN-R-29. Special multi-section winding insures greatest safety factor due to low voltage gradient between sections. Standard resistors up to 6 megohms, 6 KV, 0.5% tolerance. Higher resistance and closer tolerances available. MFA 9-25/32 inches long x 1½ inches diameter. MFB 5⅝ inches long x 1½ inches diameter.



Encapsulated Precision Wire Wound Resistors

RPC Type L Encapsulated Resistors will withstand temperature and humidity cycling, salt water immersion and extremes of altitude, humidity, corrosion and shock without electrical or mechanical deterioration. Type L resistors are available in many sizes and styles ranging from sub-miniature to standard with lug terminals, axial or radial wire leads. Available for operation at 105° C. or 125° C. ambient temperatures. These resistors will meet all applicable requirements of MIL-R-93A, Amdt. 3. Type L can be furnished with all resistance alloys and resistance tolerances from 1% to .02%.

RESISTANCE PRODUCTS CO.

914 S. 13th STREET HARRISBURG, PENNA.

Specializing in Manufacture of Resistors

TOTAL WEIGHT ONLY 22 lbs.!

(including 1" Thick Lead-Shielded Probe)

Single, compact, HAND-PORTABLE scintillation count rate meter

TO DETECT SLOW NEUTRON, FAST NEUTRON, ALPHA, BETA, GAMMA AND X-RAYS

- Built-in discriminator detects different levels of radiation from 70 KEV to cosmic
- Transistorized, high-gain circuit equivalent to that found only in expensive non-portable laboratory instruments
- Operates from line and/or standard 1½-volt batteries

The UAC #522A, pictured above in operation at Bellevue Hospital, New York, offers you new versatility in radiation detection instruments. It comes complete with transistorized ratemeter circuit, scintillation probe, directional lead-shielded probe, and thallium activated sodium iodide crystal for gamma detection. Interchangeable Slow Neutron, Fast Neutron, Alpha, Beta, and X-Ray detectors also available. Write today for full details. Also ask about #522B, encased in rugged, watertight 18" aluminum case with luggage-type handle for convenience in carrying.

AT THE TRADE FAIR OF THE ATOMIC INDUSTRY — CHICAGO — Sept. 24-28 — Booth No. 420

SEE UAC Transistorized Detection Instruments and Transistorized Power Supplies in Operation

Universal Atomics Corp.

Dept. N46 [illegible] PLaza 8-1520

for development, design, and manufacture of complete nuclear-reactor systems, cores, heavy components, steam generators, etc. (*149–151*)

Combined Book Exhibit, Inc., New York, N. Y. Display of books and periodicals on atomic energy from a broad group of publishers, arranged by subject categories and supported by a printed bibliography to be distributed on request. (*422, 423*)

Commerce Clearing House, Chicago, Ill. Atomic Energy Law Reports—loose-leaf publication covering atomic energy laws and practice surrounding the commercial, industrial, research and military use of atomics. Includes statutes, amendments, regulations, decisions, rulings, authoritative comment, check lists, industrial uses, Congressional actions. Weekly reports to keep subscribers in touch with latest information on controls concerning use of atomic energy. (*419*)

Corning Glass Works, Corning, N. Y. Radiation-shielding windows; three glass compositions to fit every shielding requirement; sizes ranging from small bricks to completely packaged units ready for insertion in cell wall; windows for safe, permanent shielding; facilities to design windows to specific requirements. (*306, 307*)

Consultants Bureau, New York, N. Y. Journal of Atomic Energy (USSR) in English translation; material on radiation chemistry and radiobiology. (*141*)

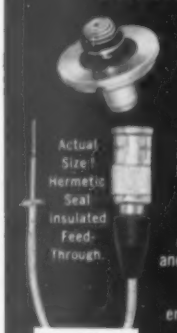
Crane Co., Chicago, Ill. Valves for radioactive and other services associated with nuclear-energy piping installations. Fittings and fabricated piping for similar services. Range of these products covers carbon steel and many alloy materials together with specialized engineering and testing facilities. (*336, 337*)

Crawford Fitting Co., Cleveland, O. Swagelok tube fittings: connectors, elbows, tees, unions, adapters, inserts, plugs, caps, reducers, quick-connect

Control console for a medical-research reactor. Daystrom, Inc.

R. S. LANDAUER, JR. & CO.
RADIATION SAFETY . . .
America's finest film badge service
COMPLETE FILM BADGE PROGRAM
covering exposure to
• GAMMA • NEUTRON
• BETA • X-RAY
RADIATIONS
for details write to:
R. S. LANDAUER, JR. & CO.
24 PLAZA - PARK FOREST, ILL.

how to complete coax assemblies successfully



MICRODOT, pioneer in micro-miniature circuitry, offers complete assemblies in any quantity. Write today and describe the coax solutions you require. With Microdot cables and over 300 Connectors, our engineers can quickly and economically supply guaranteed solutions giving you superior environmental performance and operating characteristics.

MICRODOT
1826 FREMONT ST.
SO. PASADENA, CALIF.

fittings, and thermocouple-style male connections in all machinable metals and plastics; three types of Goop thread lubricants that prevent galling. Socket-weld fittings. Swagelok-to-butt and socket-weld fittings in steel. Bulkhead adapter. (*413, 414*)

Cuno Engineering Corp., Meriden, Conn. Products suitable for primary system cleanup and/or resin retention. Poro-Klean, a corrosion-resistant sintered-metal filter; Flo-Klean, a wire-wrapped filter using continuous backflush cleaning; Micro-Klean, a felted throwaway micronic filter; and Auto-Klean, an edge-type disk filter using manual or automatic in-service cleaning. (*128*)

Daystrom, Inc., Nuclear Products Division, Elizabeth, N. J. Research and medical types nuclear reactors. Complete line of reactor-control instrumentation for all types of nuclear reactors. Miniaturized and transistorized reactor-control instruments. Standard and custom-built components or consoles for experimental control systems. Reactor simulators, neutron spectrometers, and associated equipment for nuclear research. Research and developmental facilities for specialized problems. (*247*)

DeVry Technical Institute, Chicago, Ill. Practical residential and home training in electronics. Specialized programs to prepare technicians to operate and maintain electronic instruments used in the nuclear field. Basic preparation for study and operation of radiation detectors, counters, scalers, count-rate meters, etc. Experienced counselor to advise on special training programs for picked personnel without interfering with their regular employment. (*209*)

Edward Valves, Inc., East Chicago, Ind. Specialized valves for the nuclear industry. (*123, 124*)

Edlow Lead Co., Columbus, O. Isotope-shipping cask; lead bricks; lead hot-cell components. (*436*)

Electronic Associates, Long Branch, N. J. PACE analog computing systems and their associated output equipment. (*347, 348*)

Encyclopaedia Britannica, Chicago, Ill. Encyclopaedia Britannica and Britannica Research. (*157*)

Farnsworth Electronics Co., Fort Wayne, Ind. (*244, 245*)

Flanders Mill, Riverhead, N. Y. Air filters of extremely high efficiency, used by atomic energy installations for the removal of radioactive particles in

Wherever human hands are threatened, you will find a place for the General Mills Mechanical Arm. It performs with uncanny precision and strength in radio-active areas, chemically toxic atmospheres and explosive installations.

Fully-coordinated controls make the Mechanical Arm an extension of the operator's own hand—with a greater range of movement and more power than any human!

Send now for illustrated booklet on the Mechanical Arm.

MECHANICAL DIVISION
OF General Mills
Write Dept. N9, 1620 Central Avenue
Minneapolis 13, Minnesota

careers in peaceful applications of atomic energy

REACTOR ENGINEERS

Education: B.S. or M.S. in Engineering.

Experience: 2 or more years of practical Reactor Design.

Duties: Engineering of overall reactor installations with emphasis on the mechanical and thermo design.

REACTOR SHIELDING ENGINEERS

Education: B.S. or M.S. in Engineering, Physics, or Mathematics.

Experience: Minimum of one year of practical reactor shielding analysis.

Duties: Analysis of neutron and gamma-ray distribution and shielding for nuclear reactor systems.

NUCLEAR ENGINEERS

Education: B.S., M.S., or Ph.D. in Engineering or Physics.

Experience: 0 to 5 years of practical nuclear analysis.

Duties: Analysis of critical mass optimum cell dimensions, flux distributions, control rod worth, and temperature coefficients for reactors.

SYSTEMS ENGINEERS

Education: B.S., M.S., or Ph.D. in Electrical Engineering.

Experience: 0 to 5 years experience in control and systems analysis. Nuclear background desirable but not necessary.

Duties: Analysis of reactor instrumentation and control systems, using digital and analog computers.

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

CONTACT: Mr. G. W. Newton, Personnel Office, Dept. N, 21600 Vanowen St., Canoga Park, California

(In Suburban San Fernando Valley, Los Angeles)

the submicron range. Filters in two types, organic and inorganic, and in various sizes of each type 30–5000 cfm at a 1-in. water gage pressure drop. (Efficiencies for all filters are 99.95% on 0.3-micron smoke.) (*310*)

Florida Development Commission, Tallahassee, Fla. Agency of State of Florida established by legislature to assist industrial prospects in seeking locations, making contacts, etc. Factual and statistical data on communities of the state, market studies and analyses and coordination of research activities pertinent to development. Internal improvement operation for advancement of physical needs of growing areas. (*154*)

Ford Instrument Co., Long Island City, N. Y. Closed-cycle gas-cooled reactor, 8th reactor type, for land-based power, and for ship propulsion. Reactor control and instrumentation systems and control components. Model of a CCGCR ship-propulsion system is shown. (*130, 131*)

Foster Wheeler Corp., New York, N. Y. Design for a single-region aqueous homogeneous power reactor exhibited in a "scene-in-action" display. Design and construction of nuclear power reactors for land and ship installation; swimming-pool-type research reactors; components for all reactor systems.

General Regulator Corporation: control-rod actuator. (*405, 406*)

Display of remote-handling equipment. General Electric, Atomic Power Equipment Division

General Electric Co., Schenectady, N. Y. Company's role in the peacetime atomic energy field. Model of the atomic generating plant that G. E. will build for the Commonwealth Edison Co., a simulated-action model of the G. E. dual-cycle boiling-water reactor—heart of the Commonwealth Edison plant and a model of the

G-E 12.5-Mw single-cycle boiling-water reactor. (*212–217, 312–317*)

General Mills, Mechanical Division, Minneapolis, Minn. Mechanical arm, a remote-handling mechanism capable of handling delicate glassware or heavy machinery weighing up to 750 lb. Specialized electromechanical equipment for atomic-energy installations. Research. (*158, 159*)

General Precision Laboratory, Inc., Pleasantville, N. Y. Industrial and institutional closed-circuit television equipment including cameras, control units, switchers, monitors, remote control, projection systems. (*146, 147*)

Goodyear Aircraft Corp., Akron, O. GEDA A-14 nuclear-reactor-and-power-plant simulator as described in Goodyear Engineering Report No. 7648; A-14 analog computing equipment adapted for nuclear industry application. (*447, 448*)

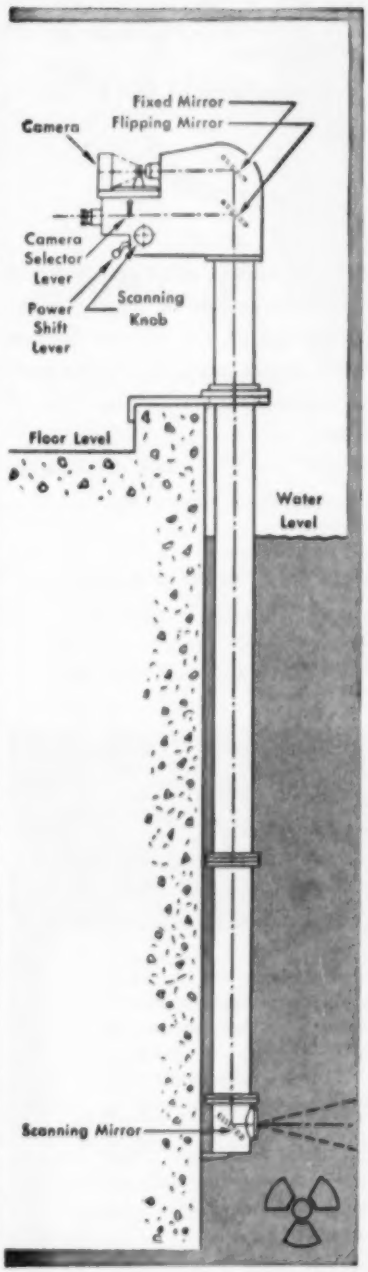
Griscom-Russell Co., Massillon, O. Steam generators and superheaters (heat supplied by reactor coolant or reactor circulating-fuel systems); intermediate heat exchangers to transfer heat from reactor coolant to secondary fluid; gas-turbine air heaters (heat supplied by reactor coolant or reactor circulating fuel system); regenerators for nuclear-powered gas turbines; unusual designs for special heat transfer problems. (*146, 147*)

Hamner Electronics Co., Princeton, N. J. Vari-Flex modular chassis, regulated low-voltage power supplies; mercury-switch pulser; scaler; nonoverload amplifier; photomultiplier preamplifier; high-voltage power supply; single-channel analyzer. (*345*)

Hevi-Duty Electric Co., Milwaukee, Wis. Hevi-Duty muffle, combustion tube, crucible and molybdenum furnaces for laboratory use available in wide range of sizes with operating temperatures up to 3000° F. Larger size vacuum, salt-bath, atmosphere and other special furnaces for industrial heat treating and production applications designed to meet particular requirements. Dry-type transformers up to 2000 kva, constant-current regulators used in obtaining metals for reactors. (*427*)

High Voltage Engineering Corp., Cambridge, Mass. Van de Graaff particle accelerators and microwave linear accelerators for production of radiation energy used in sterilization and applied chemical research. Facility for radiation available to industry for experimental purposes. Accelerators used as precise research tools in nuclear

UNDERWATER PERISCOPE



for
REMOTE
OBSERVATION
and PHOTOGRAPHY

a typical solution to problems involving

- RADIATION
- HEAT
- PRESSURE
- TOXIC GAS

A Kollmorgen Periscope may be the answer to your remote viewing and control problem. In most cases a scope of standard design and construction will meet the requirements. Where engineering is necessary, we are fully equipped to handle any design or engineering problems.

If you have a project calling for an industrial type periscope or for any precision optical system, check with Kollmorgen. For nearly half a century, we have designed, developed and manufactured precision optical products including Naval Periscopes, Fire Control Devices, Projection Lenses and Navigational Instruments for Industry and for the Armed Services.

check these advantages

- ***True Color***
- ***Sharp Definition and Clarity***
- ***Completely Reliable***
- ***No Operating Cost***
- ***Low Maintenance Cost***
- ***Photo Accessories Available***
- ***Selective Magnification***

Send for Bulletin 301.

KOLLMORGEN Optical CORPORATION

Northampton, Massachusetts

"LINDE" M.S.C. rare gases are the purest obtainable

Trade-Mark

• Helium • Argon
• Neon • Krypton
• Xenon

LINDE rare gases are produced under continuous mass spectrometer control to assure you of gases of *known* purity and consistently high quality. They are stocked at convenient locations throughout the country in glass bulbs and steel cylinders. LINDE, the world's largest producer of gases from the atmosphere, offers the services of its technicians and engineers to all of its customers on their rare gas problems.

Write for the booklet, "LINDE Rare Gases" which contains information on the physical, chemical, and electrical properties of these gases.

Linde Air Products Company

A Division of Union Carbide and Carbon Corporation

30 East 42nd Street UCC New York 17, N. Y.

The term "Linde" is a registered trade-mark of Union Carbide and Carbon Corporation.

...for many different applications
SINCE 1901
Electroplated WIRE
More and more people are turning to us for electroplated wire. We electroplate by continuous methods a wide variety of wire in a range of diameters from .035" to the smallest available. In our laboratory, Tungsten wire as small as .00015" has been electroplated with Gold... New applications for electroplated wires on different base materials are being developed from time to time . . .
Your inquiry is invited. Consult our staff, without obligation, about your specific wire problems.
Specialists in the Unusual
SIGMUND COHN MFG. CO., INC.
121 SO. COLUMBUS AVE., MOUNT VERNON, N. Y.

physics and as supervoltage X-ray generators for medical therapy and industrial radiography. (*111, 112*)

Holmes & Narver, Inc., Los Angeles, Cal. Technical reports on shielding and blast effects; services of engineers experienced in this field for application to problems of peacetime and industrial installations. (*426*)

Ionics, Inc., Cambridge, Mass. Model electrolytic reduction-precipitation cell for the production of green salt (UF_4). Slides showing role of cell in an improved process for preparing uranium feed materials from ore leaches or reprocessed fuel. Material on work of nuclear department in chemical technology, reactor-coolant purification, ion exchange, and trace and radiochemical analysis. (*434*)

Jarrell-Ash Co., Newtonville, Mass. Spectrographic equipment consisting of high-resolution, high-dispersion spectrograph; multiple-discharge sample-excitation source; console-comparator microphotometer for interpolation and reading of spectrograms; uranium fluorimeter for quantimetric analysis of uranium; Hilger Microfocus X-ray unit for diffraction analysis. (*458, 459*)

Jordan Electronics, Inc., Alhambra, Cal. Model RAMS-11 for radiation monitoring utilizing all a-c circuitry, monitoring up to 20 remote stations from one control unit; logarithmic scales providing 3 decades per range are used; portable radiation-measuring instruments for detection of alpha, beta, or gamma; dosimeters; dosimeter chargers; γ-ray spectrometers. (*425*)

O. G. Kelley & Co., Dorchester, Mass. Special equipment to furnish "hot" laboratories with protection need through installation of ray-stopping barriers such as lead shielding for walls, lead bricks, lead containers and vaults, isotope vaults, caskings, lead-filled doors, lead observation win-

Heaviest piece of clad steel ever rolled is for Duquesne's Shippingport reactor. Lukens Steel Co.

dows with X-ray lead glass, lead valves and pumps, stainless-steel hoods and various types of stainless-steel process equipment. (*122*)

Walter Kidde Nuclear Laboratories, Garden City, N. Y. Comprehensive consulting service to the nuclear industry. Design of reactors, radiation facilities, liquid-metal systems, fuel processing, waste handling. Hazards studies, site surveys, review of designs, shielding studies, model-making. Experimental facilities for component testing, hydraulic and heat-transfer studies, corrosion studies, radiochemistry, fission-product applications. (*119*)

Knapp Mills, Long Island City, N. Y. Use of lead and lead-clad metals in shielding against the escape of gamma radiation. Information on equipment such as shipping containers, core-handling facilities, shielding for shipboard reactors, etc. Newly invented Raysist shielding log. (*241*)

Kollmorgen Optical Corp., Northampton, Mass. Industrial periscopes and borescopes for remote observation and photography. (*335*)

Leeds & Northrup Co., Philadelphia, Pa. Model power-reactor generation station, model of boiling-water reactor using an electronic nuclear-reactor-simulator working model of a boiling-water-reactor core and a simulated steam-turbine generator. Nuclear, steam, and load-frequency control systems showing "on-the-line" performance. (*203–205, 303–305*)

P. M. Lennard Co., Brooklyn, N. Y. Safety boxes, glove boxes, fume hoods, lead-rubber gloves, dry boxes and building material. (*404*)

Linde Air Products Co., New York, N. Y. Linde MSC rare gasses; helium, neon, argon, krypton, and xenon and high-purity diatomic gasses, with emphasis on properties that make these gasses valuable in nuclear processes. Model of Cascade and Driox bulk storage units. (*114–118*)

Lindsay Chemical Co., West Chicago, Ill. Rare earth and thorium chemicals produced by both classical and ion-exchange-purification methods; ion-exchange column shown in operation. Rare earth salts ranging from commercial mixtures to extremely high purities; thorium salts in commercial and reactor grades. (*202*)

Lukens Steel Co., Coatesville, Pa. Lukens clad steels offering high corrosion resistance and oxidation resistance; light- and heavy-gage stainless-clad steel pipe for high-pressure piping

New Air Particle Monitor

from

ANTON

..Where Precision Counts

Anton's monitor enables continuous, unattended recording of airborne alpha, beta or gamma radiation with sensitivity never before available in instruments of this type. The monitor, ideal for reactor, fuel processing and hot lab installations, can operate at gamma background as high as 10 mr /hr. The unit has a sensitivity range of 8 x 10^{-10} μc /cc to 8 x 10^{-7} μc /cc as calibrated with Na^{24}, and incorporates visible and audible, immediate or remote alarms adjustable over the operating range. Built-in calibrated source insures accuracy and performance of the instrument's detector and related circuitry. Special circuit failure indicator check switch connects the panel meter to key circuit points for easy trouble shooting. Anton monitoring instruments and systems include the latest developments resulting from fundamental research work on system production for reactor facilities and naval nuclear-powered vessels.

Anton's monitor is available either as a cart-mounted mobile unit or rack-mounted for use as a fixed station. Mobile unit, MODEL 232, is set on a welded, reinforced steel cart; MODEL 233 has all equipment mounted in a 19-inch relay rack. (*Request Bulletins 232, 233*)

TECHNICAL DATA

Precision	**Better than 1% of full scale meter deflection**
Stability	**Better than 0.5% of full scale meter deflection**
Filter paper advance	**Continuous: at ½ inch/hour**
	Manual (when necessary): by external control knob
Pulse discriminator	**Rejects small "noise" pulses**
Air pump	**Positive displacement, oil-less, requires no lubrication**
Recorder	**12 inch chart, speed adjustable from ½ to 8 inches per hour**
Power	**Nominal 117 v, 60 c.p.s.**
Weight	**Net 450 lbs.**
	Shipping 500 lbs.

TRAILER-MOUNTED SURVEY LABORATORIES

This monitor is incorporated in the new Anton mobile radiological laboratory trailers which contain complete field equipment for reactor site survey teams, fire fighting, police and civilian defense forces. (*Request Bulletin TM*)

Anton also manufactures a full line of tubes and instruments for research, medical and industrial counting applications. (*Request Bulletin 4P*)

Please visit Anton in Booth 100 at the 1956 Trade Fair of the Atomic Industry

ANTON ELECTRONIC LABORATORIES, INC.

A subsidiary of U. S. Hoffman Machinery Corporation

1226 FLUSHING AVE., BROOKLYN 37, N. Y.

YOURS for the ASKING

A copy of this quick-reading, 8-page booklet is yours for the asking. It contains many facts on the benefits derived from your business paper and tips on how to read more profitably. Write for the "WHY and HOW booklet."

McGraw-Hill Publishing Company, Room 2710, 330 West 42nd St., New York 36, N. Y.

in reactor systems; clad steel plates for heat exchangers and pressure vessels with a variety of backing steels to meet high-pressure, high-temperature conditions. (*236, 237*)

Mallinckrodt Chemical Works, Special Metals Division, St. Louis, Mo. Uranium dioxide, produced from uranium hexafluoride withdrawn from a gaseous-diffusion cascade. A ceramic type oxide for use in fabrication of high-density fuel-element pellets. Also a dense high-fired oxide for use in fabricating ceramet matrix-type fuel elements. Uranium compounds of degrees of enrichment from normal to top product grade; other uranium compounds. (*324*)

Glenn L. Martin Co., Nuclear Division, Baltimore, Md. Package power reactor with design capabilities of 500 to 5000 kw. Complete plant shippable in seven structural pods, used as permanent housing at site, requiring only days to put into operation. It is designed to operate in climatic conditions ranging from arid to humid, from the tropics to the Arctic. (*235*)

Massachusetts Department of Commerce, Boston, Mass. Nuclear installations, actual and potential in and around Massachusetts. Maps and photographs showing educational, cultural and transportation advantages; a pictorial representation of the state's major research facilities following theme of "climate of creativity." (*321*)

McGraw-Hill Book Co., New York, N. Y. Technical books covering all aspects of the nuclear industry, including the new Progress in Nuclear Energy Series, six USAEC titles, the McGraw-Hill series in Nuclear Engineering, as well as the complete National Nuclear Energy Series. Leading new books on chemical engineering, physics, and mathematics. (*129*)

Metals & Controls Corp., Nuclear Products Division Attleboro, Mass.

Salt bath and hot-rolling mill for fabrication of uranium and alloy plates. Metals and Controls Corp.

Fuel elements and fuel-element components. Complete facilities for fabrication of enriched and normal uranium, thorium, zirconium and alloys. Thin-gage foils, wire, pellets, rod, tubing, assemblies, uranium oxide-metal combinations and special shapes. Metal-working and supporting equipment available for rolling, bonding, extrusion, forging, slitting, arc melting, induction melting, etc. (*322, 323*)

Michigan Chemical Corp., Saint Louis, Mich. Chemical products for the atomic industry. (*421*)

Mine Safety Appliances Co., Pittsburgh, Pa. Ultra-Aire space filter with high-temperature model; filter media; Fixt-Flo air sampler; Dustfoe ultra-filter respirator; Comfo ultra-filter respirator. (*452, 453*)

Minneapolis-Honeywell Regulator Co., Industrial Division, Philadelphia, Pa. A nuclear reactor simulator with automatic startup, useful for training and demonstration. Includes simplified safety amplifier using relays to initiate complete, fast break, combined log-N and period amplifier, log count-rate meter, low-level period amplifier, and automatic three-mode rod-position controller. ElectroniK recorders with special charts and scales for power-level, flux-density and period readings. (*104*)

National Carbon Co., New York, N. Y. High-purity graphite for use in reactors; nuclear graphite used as moderator, reflector, shield, thermal column; graphite molds and crucibles used in processing methods. (*114–118*)

Furnace for vacuum melting, casting, heat treating of nuclear metals. National Research Corporation

NEW!

JORDAN RAMS II

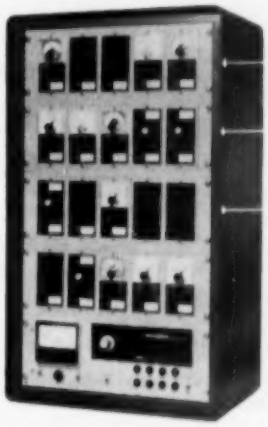
Remote Area Monitoring System

FILLS YOUR RADIATION MONITORING NEEDS

Ruggedized . . . Stabilized . . . with Improved Reliability

- Simplified operation
- Reduced maintenance and installation costs
- AC circuit, 110V, 60cy (no batteries)
- Monitors up to 20 channels from ONE control unit
- All features of RAMS I and its accessories combined in integrated station units
- Each station unit panel contains all indicators and controls for that channel
- Chambers can be located up to 2 miles from the control unit (without secondary amplification)
- Start with one control unit and one station unit panel and expand system as required

32 *types of standard plug-in station units are available from stock*



STATION PANELS ADDED AS NEEDED

4 BASIC STATION UNITS:

1. **NON-INDICATING** (Read meter on control panel)
2. **INDICATING METER** (For continuous monitoring)
3. **METER RELAY** (To actuate alarm circuits)
4. **INDICATING METER RELAY** (To actuate alarms and monitor continuously)

EACH of the 4 basic station units is available with choice of:

1 or 2 ranges of 3 logarithmic decades each providing 1 : 1,000 range without switching . . . Accuracy equal for any level.

Remote calibration check source . . . to verify accuracy at any time.

Small: (CG-1) Chamber for high radiation intensity (10mr/hr - 100,000r/hr) and up . . . Large: (CG-50) Chamber for fast response at low levels (Below 10mr)

In-Stock plug-in units offer simple modification to satisfy changing requirements.

Monitors up to 20 channels from ONE control unit . . . available in any number of station units desired (1-20).

All station units are provided with output to operate a 10 mv. potentiometer recorder.

REPRESENTATIVES IN PRINCIPAL CITIES

for informative brochure and complete technical data, write:

See the RAMS II at the Trade Fair of the Atomic Industry Sept. 24-28 Chicago, Ill.

JORDAN ELECTRONICS, INC.

A subsidiary of PANELLIT, INC.

(DEPT. N-2) 3025 W. MISSION RD., ALHAMBRA, CALIF.

NOW-a

Fast Neutron Survey Meter

National Radiac

Egg-Head

FOR

Health Hazard Protection

- Excellent response at low flow levels
- 3 ranges: 0-7.5 mrem/hr, 0-75 mrem/hr, 0-750 mrem/hr
- Good gamma discrimination
- Non-directional sensitivity
- Line operated & portable models

Designed for health protection in areas where fast neutrons are present, the Egg-Head measures radiation at any single moment and provides meter readings in terms of hourly dosage. A phone jack is also provided for audible detection.

Three Models Are Available:

Model E-1 —line operated laboratory monitor ..... $605.

Model E-1A —lightweight battery operated laboratory monitor ..... $595.

Model EP —lightweight battery operated portable monitor ..... $595.

MODEL EP

For literature and detailed specifications, write: Dep't. A-7

National Radiac INC.

475 Washington St., Newark 2, N. J.

National Lead Co., New York, N. Y. Shielding materials and methods including lead in various forms, concrete densified with barite, magnetite, and lead. Metals for reactor construction and operation. (*105, 106*)

National Research Corp., Cambridge, Mass. Equipment: vacuum furnaces used in melting, casting, and heat treating nuclear metals and alloys; vacuum components: gas ballast pumps, diffusion pumps, valves, and gages. Materials: NRC Metals Corporation's reactor-grade zirconium and zirconium chemicals. Research: process metallurgical facilities for melting, casting, heat treating, coating; physical metallurgical test facilities. (*308, 309*)

Newport News Shipbuilding & Drydock Co., Newport News, Va. Model of 5-Mw homogeneous reactor vessel; core vessel of reactor is all-welded zirconium alloy; panels of weld and test samples of zirconium. Conceptual model of cargo ship powered by pressurized water reactor similar to Nautilus installation. (*101, 102*)

Nuclear Development Corp. of America, White Plains, N. Y. Research, development, and engineering in the nuclear field specializing in reactors and components. Research and engineering laboratories, computing center, and nuclear experiment station containing a critical facility and hot laboratory. Reactor model, nuclear controlled-environment capsule, liquid-metal-level indicator. (*342*)

Nuclear Metals, Inc., Cambridge, Mass. Research and development specializing in reactor materials—uranium, thorium, zirconium, beryllium, alloys, oxides and cermets. Fully equipped metallurgical laboratory; foundry; metallographic, analytical, radiation-damage, corrosion testing and metal-working facilities including 100-, 300-, 1000-ton extrusion presses. Specialists in melting, casting, extrusion and coldfinishing operations. (*435*)

Nucleonics, N. Y., N. Y. (*223*)

Pergamon Press, New York, N. Y. International research journals such as the *Journal of Applied Radiation and Isotopes* and the *Journal of Nuclear Energy*, and books in the fields of science and technology—the Progress in Nuclear Energy Series based on the Geneva Conference on Peaceful Uses of Atomic Energy, the International Series of Monographs on Nuclear Energy, etc. (*432*)

Pittsburgh Piping & Equipment Co., Pittsburgh, Pa. Fabricated piping,

Now in Use in Thousands of Labs!

PROPIPETTE

The safe accurate Pipette Filler for Isotopes, Cyanides, Acids, Bacteria and Other Dangerous Solutions

This amazing new instrument is now standard equipment in government, medical and industrial laboratories throughout the nation. Offers more precise measurement (to 0.01 cc), more complete control, and avoids all the risks of mouth pipetting. Holds set level indefinitely, fits any pipette, operates easily with one hand. Order a supply of PROPIPETTES now, **$6.90** each

INSTRUMENTATION ASSOC.

17 West 60th Street, New York 23, Dept. P. 5

Circle 5-5591

Send for current list of new scientific instruments

Reactor Components

Use Vacuum Brazing

KINETICS INTRODUCES A NEW SERVICE TO INDUSTRY

Vacuum Brazing produces homogeneous bonds that are *completely* void free even over large surface areas. Superior purging, wetting and flow characteristics under vacuum virtually eliminate rejects. Complex multiple assemblies can be successfully brazed in a single operation.

Degassing purifies both the parent metals and brazing material. This results in a stronger, more ductile bond.

KINETICS VACUUM BRAZING SERVICE IS AVAILABLE FOR CONTRACT OR EXPERIMENTAL WORK. WRITE FOR MORE INFORMATION.

KINETICS CORPORATION

pressure vessels, and related equipment for atomic-energy installations and central power stations; process piping for industry; stainless-steel piping for nuclear-energy installations. *(132, 133)*

Quartermaster Food & Container Institute for the Armed Forces, Chicago, Ill. Essential objectives in expediting commercial applications of the radiation preservation of foods. Potentials of radiation sources; examples of foods irradiated at different levels; applications of radiation; idealized version of a radiation-preservation production line. *(142–144)*

Radiation Applications, Inc., New York, N. Y. Physicists, engineers, chemists, geneticists, biologists and mathematicians to assist in the exploration and development of applications of radiation to commercial products and processes; consultation and research services; Radiation Applications, monthly technical review. *(441)*

Radiation Counter Laboratories, Skokie, Ill. 256-channel magnetic-memory pulse-height analyzer; reactor control systems. *(351)*

Republic Steel Corp., Cleveland, O. Enduro Stainless Steel used in structures and equipment for research and production of atomic energy and radioactive isotopes, in laboratory equipment; atomic power plant heat exchangers and equipment for reactors and atomic energy components. Titanium used in applications requiring high strength, low weight, and excellent corrosion resistance. *(220–222)*

Robertshaw-Fulton Controls Company, Fulton-Sylphon Division, Knoxville, Tenn. Temperature controls, packless valves, bellows, bellows assemblies. *(224)*

Scientific American, New York, N. Y. Scientific American magazine and other publications of interest to individuals in atomic energy. *(152)*

Superior Tube Co., Norristown, Pa. Tubing samples in 63 standard and 60 special analyses in size range .010–⅝ in. od, and certain analyses up to 2½-in. od in light walls; tubing made from the reactive metals, zirconium, and zirconium alloys; fabricated components for nuclear reactors from Nuclear Products Division. *(440)*

Sylvania Electric Products, Inc., Atomic Energy Division, Bayside, N. Y. Preparation and development of nuclear fuels and reactor components such as moderators and control elements. Display of fuel elements and control rods and three-dimensional model of a graphite-moderated reactor

(above) Nuclear-Chicago scintillation detector is lowered into water for tracing the radioactive sewage effluent at varied depths over a 25 square mile area. (right) Gamma-ray spectrometer system, ratemeter and recorder on laboratory ship measure and chart traces of radioactive scandium during 36-hour period of experiment.

RADIOACTIVITY HELPS PREVENT BEACH POLLUTION FROM SEWAGE EFFLUENT

In a unique experiment just completed in Santa Monica Bay, California, radioactive isotopes were successfully used to trace the dispersion of sewage effluent in ocean waters. The results are helping to establish proper design procedures to insure against beach pollution in a current expansion of the Los Angeles sewage system.

The tracer experiment was a joint project of Hyperion Engineers, Nuclear Science and Engineering Corporation and the Hancock Foundation of the University of Southern California. Twenty curies of scandium-46 were mixed with sewage effluent and discharged into the sea. Scientists aboard a laboratory ship then took radioactive measurements over a wide area to determine dilution rate and direction of diffusion.

Since this was a "one-shot" experiment, the dependability and overall sensitivity of the equipment were extremely important. The instruments chosen, including the DS5-3 scintillation detector, 1810 gamma-ray spectrometer, 181 scaler and 1620 ratemeter were standard Nuclear-Chicago catalog items.

nuclear-chicago

NUCLEAR INSTRUMENT AND CHEMICAL CORPORATION
235 West Erie Street, Chicago 10, Illinois
LEADERS IN MAKING RADIOACTIVITY COUNT

HIGH VOLTAGE
AS STABLE AS BATTERIES

Hamner

N-401 Regulated High Voltage Supply

... for Scintillation Spectroscopy • Proportional Counters
General Laboratory Use

- **RANGE:** 500-1800 volts continuous 5 MA, neg. or pos.
- **NOISE & RIPPLE:** less than 1 MV RMS
- **STABILITY:** against line changes, 3 PPM per volt at 1000V
- **OUTPUT IMPEDANCE:** 2.5 ohms
- **REGULATION:** 2.5 PPM per MA at 1000V
- **TRANSIENT RECOVERY TIME:** 80 microseconds

The N-401 represents a new concept in power supply circuitry—a development providing stability hitherto available only in batteries. The reference elements have a stability of better than 10 PPM per hour. Any desired voltage can be selected to better than 0.3 volt over the entire range.

Price $455.00 FOB Princeton
(subject to change)

Send for literature

Hamner Electronics Co., Inc.
P.O. BOX 531, PRINCETON, N.J. • PEnnington 7-1176

free send for the most widely used
ELECTRONIC SUPPLY GUIDE

ALLIED'S
COMPLETE 356-PAGE
1957 CATALOG

We specialize in Electronic Equipment Supply for Research, Development, Maintenance and Production

COMPLETE EXPERT INDUSTRIAL SERVICE

One complete dependable source for Everything in Electronics

Our 38th Year

your buying guide
to the world's largest stocks of
ELECTRONIC SUPPLIES FOR INDUSTRY

Simplify and speed your purchasing of electronic supplies and equipment: send your orders to ALLIED—the reliable one-supply-source for *all* your electronic needs. We make fastest shipment from the world's largest stocks of electron tubes (all types and makes), transistors, test instruments, audio equipment, electronic parts (transformers, capacitors, controls, etc.), and accessories—*everything* for industrial and communications application. Our expert Industrial supply service saves you time, money and effort. Send today for your FREE copy of the 1957 ALLIED Catalog—your *complete* Buying Guide to quality Electronic Supplies for Industrial and Broadcast use.

ALLIED RADIO
100 N. Western Ave., Dept. 57-J-6
Chicago 80, Illinois

Send for FREE Catalog

illustrating various types of fuel elements and control rods. (*109, 110*)

Technical Associates, Burbank, Cal. Instrumentation for nuclear research; personnel monitors; scalers; radiation-survey meters—"Cutie Pie" and "Juno"; lead shields and accessories; G-M, scintillation counters; absorber sets; film-badge service; ionization chambers, chemical dosimeters. (*121*)

Union Carbide Nuclear Co., New York, N. Y. Role of organization in nuclear field; samples of uranium ores and concentrates, three-dimensional models of power and research reactors; showing of "The Petrified River," new motion picture produced with U. S. Bureau of Mines. (*114–118*)

United Nations, United Nations, N. Y. Sixteen volumes of Proceedings of the International Conference on Peaceful Uses of Atomic Energy held in Geneva, August, 1955, distributed in the U. S. by Columbia University Press. A definitive and unabridged report serving as standard text and basic documentation on the subject; 8-panel pictorial display on the international atom. (*325, 326, 428*)

U. S. Atomic Energy Commission, Washington, D. C. Publications and services for industry. (*164*)

United States Dept. of Commerce, Washington, D. C.

Office of Technical Services. Information services for the business community on commercial applications of atomic energy. (*162, 163*)

National Bureau of Standards—Research and development in radiation physics including material on protection, X-rays, instrumentation, neutrons; NBS publications. (*160, 161*)

U. S. Hoffman Machinery Corp., Nuclear Division, New York, N. Y. Pneumatic conveyor equipment for handling radioactive materials. (*100*)

U. S. Radium Corp., Morristown, N. J. Recent advances in design of permanently sealed radioisotope-activated industrial light and radiation sources with wide range of performance characteristics for uses ranging from stable light and color standards to marking, identification and low-level-lighting installations; hermetically sealed radiation sources used for radiation calibration, activation analysis, radiography, ionization, static elimination, inclusion in liquid-level, slurry-level, and thickness gages. (*320*)

Universal Atomics Corp., New York, N. Y. Transistorized electronic d-c-to-d-c power supplies up to 100 watts

that fit in hand; any practical combination of voltage and current from inputs to 28 volts. Units as light as 2 oz, as small as 2 in.³, deliver 2000 volts from 1½ volts input. Transistorized circuits, devices, nucleonic equipment for government and industry; transistor application consulting services. (*420*)

Victoreen Instrument Co., Cleveland, O. Reactor instrumentation, radiation-monitoring instruments and dosimeters, laboratory and field survey instruments, medical X-ray dose-control instruments, electronic components including sealed glass resistors and corona-regulator tubes. (*302*)

Vitro Corp. of America, New York, N. Y. Services in atomic energy; from mining, milling, processing, and refining uranium through engineering and construction of nuclear facilities. Research and development; thorium and monazite; rare earths and heavy minerals; refining and recovery of rare metals; facilities operation; aircraft components; high intensity arc applications. (*450, 451*)

Simulated-action homogeneous-reactor power-plant model. Westinghouse

Westinghouse Electric Corp., Pittsburgh, Pa. Models of first industry-owned atomic reactor for testing atomic fuels and materials and of the first large homogeneous reactor plant project. Atomic-plant component products including hermetically-sealed pumps and valves, nuclear fuel elements, Corox heaters, monitoring and detecting equipment. (*400–403*)

C. H. Wheeler Mfg. Co., Philadelphia, Pa. Pumps, glandless valves, heat exchangers, pressure vessels for nuclear service for stationary and marine power-plant service; steam condensers, steam-jet ejectors, circulating and condensate pumps. Development, design and manufacture of special equipment for the nuclear and power-generation fields. (*412*)

WASTE DISPOSAL

RADIOACTIVE
- Explosives
- Pyrophoric Materials
- Poisonous Gases
- Flammable Materials
- Contaminated Equipment
- Toxic Materials
- Acids and Caustics

COMPLETE SEA DISPOSAL
Serving the U.S. Since 1946

Authorized by All Necessary Federal, State and Local Authorities

CALL OR WRITE

Crossroads

MARINE DISPOSAL CORPORATION
26 T. WHARF, BOSTON, MASS.
LAfayette 3-4908

HASTINGS VACUUM GAUGES

SET NEW STANDARDS OF ACCURACY, STABILITY, RESPONSE

MODEL LV-1

- Easy To Read Scales
- Unusually Long Life
- Matched Gauge Tubes
- No Outgassing Or System Contamination

NEW MODEL LV-1. Measures 0-100 micron Hg. Single meter; large 4" scale indicates vacuum directly without adjustments. Internal voltage regulator takes care of fluctuations in line voltage. Ideal for Industrial Installations. Also available in 0-1000 micron and 0.1-20 mm Hg. ranges.

MODEL GV-3 VACUUM GAUGE

(Shown at right with optional 5-position switching attachment) Range from 0-1000 microns Hg. Manual current set and additional milliampere scale allow adjustment for use in presence of gases other than air, for leak detection, and for specialized laboratory use.

Evaluation by Users
PROVES SUPERIORITY
of Hastings Gauges
WRITE:

HASTINGS-RAYDIST INCORPORATED
HAMPTON 14, VIRGINIA
PHONE 3-6531

HOW

IONICS

SERVES

the

ATOMIC INDUSTRY

Good nuclear reactor development requires such an array of scientific talent that few reactor builders or processors of nuclear materials find it convenient or profitable to employ all of the specialists required. Instead, they turn to a specialized research and development firm to supplement their own staff.

In this way, Ionics, Incorporated, operating under subcontract, has contributed importantly to the research, design and development of chemical systems incorporated in several existing reactors and nuclear processing plants.

Ionics' specialties include:

- *Reactor coolant purification.*
- *Preparation of uranium, thorium and zirconium intermediates and feed materials.*
- *Reprocessing of nuclear fuels.*
- *Radiochemical and trace analysis.*
- *Fission waste disposal.*

Few firms can match Ionics' staff and facilities in the fields of ion exchange, ion transfer membrane technology, aqueous and solution chemistry, and chemical metallurgy.

For information on how Ionics can advance your nuclear research and development program write Department NM.

Ionics, Incorporated

152 Sixth Street

Cambridge 42, Mass.

See our exhibit on work in the nuclear field at Booth 434, 1956 Atomic Trade Fair.

PRODUCTS AND MATERIALS

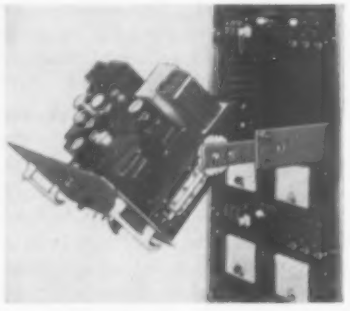
Counting-Rate Meter

New counting-rate meter (above) for industrial use, capable of G-M or scintillation counting, converts pulses for analog interpretations of up to 100,000 cpm with 2% meter accuracy, less than 2% resolution loss. Switch selects the integrating time constant at 2, 10, and 50 seconds. Input sensitivity is 0.25 volts.—Berkeley Div., Beckman Instruments, 2200 Wright Ave., Richmond 3, Cal.

Filter Pumps

Self-priming filter pumps for filtering corrosive solutions are available in two models handling from 50 to 300 gph. Pumps are of stainless steel with neoprene impeller and high-temperature lucite filter assemblies mounted on linen-impregnated phenolic panels and are coupled to a totally enclosed ¼ hp motor.—Sethco Mfg. Co., 70-78 Willoughby St., Brooklyn 1, N. Y.

Shielded syringes. Volumes of 1–10 cm^3 are available in syringes shielded with ½ in. of lead—4 hvl's for radiogold.—Hamilton Co., 1134 Whitley St., Whittier, Cal.



Cabinet Slide

Chassis-Trak units permit quick servicing of electronic components in relay rack. One model tilts freely; another locks in fixed positions.—Chassis-Trak Corp., 6252 Iona Rd., Indianapolis, Ind.

Polyethylene Hoods

Canopy-type hood and exhaust-ducting system shown above are made entirely of black polyethylene. Thickness is ¼ in.; flanges are ½ in.—American Agile Corp., 5461 Dunham Rd., Maple Heights, O.

Products Index

Laboratory Instruments and Apparatus 168
Circuit Components 170
Piping Components 171
New Materials 172
Radiation Detectors and Accessories 172
Literature Available 176
Industry Notes 177

Announcing

The new McGraw-Hill Subscription Service for

McGRAW-HILL

The Library of PROGRESS IN NUCLEAR ENERGY

Under the Consulting Editorship of

J. V. DUNWORTH, C.B.E. D. J. HUGHES F. PERRIN A. M. WEINBERG

Of vital interest is the vast amount of detailed technical information stemming from the Geneva Conference. To point up its meaning and usefulness to you, this mass of information on peaceful uses of nuclear energy is now being drawn from international sources, coordinated and organized in The Library of Progress in Nuclear Energy.

Here, in the hands of a staff of experts, this material is correlated, critically revised, and edited to be of most use to workers engaged in the sciences concerned with nuclear energy. In order to take account of latest applications, the first volumes of the Library deal with papers presented at Geneva, since so much new material was declassified and given there for the first time.

Thus, among the eight books planned for release during the next few months are many that may prove to be indispensable references for you.

To bring them to you on as rapid a schedule as possible, McGraw-Hill is initiating a unique, new subscription service. As a subscriber, you will receive each book in the Library just as soon as it is published—to check, consult, and examine for 30 days on approval. Then you either place it in your permanent library or return it, as your judgment dictates.

The group of Charter Subscribers is now being formed with benefits like these planned for its members:

—As each volume comes from the press, it will be shipped automatically on approval to each subscriber. Such automatic delivery assures you of not missing any of these important volumes in the press of other responsibilities. Also, it assures you as a subscriber of receiving each volume well in advance of its general distribution.

—Each volume is sent to you on 30 days' approval. If it meets your requirements and you decide to keep it, you do so at a savings. If not, the volume is returnable—without interrupting your subscription and without affecting the special price you are entitled to on any other volume you keep.

—You save $2.00 on the purchase price of each volume you keep—a discount available only to subscribers to this Library service.

Frankly, we believe this Library subscription plan is a modern, practical solution to the problem facing all men in your field—to keep up with these important new books without having to sacrifice valuable time tracking down their publication.

Just fill in the Charter Subscriber's form below. It authorizes us to automatically send you each volume in the Library as soon as it is published. You agree only to examine and use it for 30 days on approval. No specific number of books need be purchased, and you may cancel your subscription any time you wish.

The first 8 volumes planned for subscribers are:

Series 1—PHYSICS AND MATHEMATICS

Summarizes results, and methods for their analysis, pertaining to properties of fissionable nuclei. Includes material on reactor physics, and involves techniques used in planning experiments with reactors. 410 pp., $12 ($10 to Subscribers)

Series 2—REACTORS

Series of review papers on present state of reactor physics. Included are surveys of design and operating characteristics of important research reactors throughout the world, including the Soviet Union. All power reactor programs are summarized in individual review papers. 430 pp., probable price $12 ($10 to Subscribers)

Series 3—PROCESS CHEMISTRY

Covers methods used by major countries. Treats entire chemical processing field, including recovery and purification of uranium and thorium from ore, reactor fuel processing, producing radioisotopes, selecting best radiochemical processes, etc. 450 pp., $12 ($10 to Subscribers)

Series 4—TECHNOLOGY AND ENGINEERING

Detailed surveys and descriptions of unit operations in reactor engineering. Includes heavy water production and analysis, graphite production and properties, beryllia, liquid metals, heat transfer engineering, corrosion, and high pressure chemistry. Includes material from Soviet sources. 400 pp., probable price $12 ($10 to Subscribers)

Series 5—METALLURGY AND FUELS

Detailed surveys by Geneva contributors from many nations on the metallurgy of uranium, thorium, plutonium, ceramics, and alloys used in reactors of all kinds, with equally important material on irradiation, and solid state physics. 400 pp., probable price $12 ($10 to Subscribers)

Series 6—BIOLOGICAL SCIENCES

Latest conclusions and techniques in radiation biology—animal and plant. Important material on radiation injury and protection, genetics, and tracer work. 500 pp., probable price $12 ($10 to Subscribers)

Series 7—MEDICAL SCIENCES

Contains directly medical applications of radiation biology, with definitive chapters on reproduction, diagnosis, pathological research, and the control of dosage and hazards in all radiation situations. 480 pp., probable price $12 ($10 to Subscribers)

Series 8—THE ECONOMICS OF NUCLEAR POWER

Presents a good deal of very new material, some still speculative. Economics of research reactors is developed in relation to this country and other areas, and much new information is presented in relation to industrial power reactors on the present experimental scale and with projections of future large-scale operations. 500 pp., probable price $15 ($13 to Subscribers)

EDITORS OF SERIES

F. R. Bruce (*Oak Ridge*)
J. C. Bugher (*A.E.C., Washington*)
R. A. Charpie (*Oak Ridge*)
J. Cousaget (*Saclay*)
H. M. Finniston (*Harwell*)
J. M. Fletcher (*Harwell*)
J. Guéron (*Saclay*)
S. Horowitz (*Saclay*)
J. P. Howe (*Downey, Calif.*)
D. J. Hughes (*Brookhaven*)
R. Hurst (*Harwell*)
H. H. Hyman (*Argonne*)
J. J. Katz (*Argonne*)
J. A. Lane (*Oak Ridge*)
D. J. Littler (*Harwell*)
J. F. Loutit (*Harwell*)
J. R. Maxwell (*London*)
S. McLain (*Argonne*)
J. Menke (*New York*)
M. Trocheris (*Saclay*)

EDITORIAL ADVISORY BOARD

M. Benedict (*M.I.T.*)
R. Bennett (*Schenectady*)
C. J. Bakker (*Amsterdam*)
J. P. Baxter (*Sydney*)
H. J. Bhabha (*Bombay*)
E. Bretscher (*Harwell*)
H. Brynielsson (*Stockholm*)
Sir John Cockcroft (*Harwell*)
H. Emeleus (*Cambridge*)
Sir Claude Gibb (*Newcastle*)
J. Guéron (*Paris*)
L. R. Hafstad (*New York*)
L. J. Haworth (*Brookhaven*)
M. de Hemptinne (*Louvain*)
Sir Christopher Hinton (*Risley*)
J. J. Katz (*Argonne*)
W. B. Lewis (*Chalk River*)
J. F. Loutit (*Harwell*)
H. S. W. Massey (*London*)
J. M. W. Milatz (*Utrecht*)
S. McLain (*Argonne*)
R. E. Peierls (*Birmingham*)
G. Randers (*Kjeller*)
L. Rotherham (*Risley*)
W. E. Schoupp (*Pittsburgh*)
C. Starr (*Downey, Calif.*)
R. Spence (*Harwell*)
F. H. Spedding (*Ames, Iowa*)
Philip Spoon (*New York*)
P. Scherrer (*Zurich*)
B. F. J. Schonland (*Harwell*)
Sir Francis Simon (*Oxford*)
H. W. B. Skinner (*Liverpool*)
W. H. Zinn (*Argonne*)

AVOID DELAYS!

MAIL COUPON OR WRITE TODAY TO

McGraw-Hill, Dept. FNU-9, 327 W. 41 St., N.Y.C. 36

MAIL THIS CHARTER SUBSCRIBER FORM TODAY!

McGraw-Hill Book Co., Dept. FNU-9, 327 W. 41 St., N.Y.C. 36

Please enter my name as a Charter Subscriber to the McGraw-Hill Library of PROGRESS IN NUCLEAR ENERGY. I understand that

—I will immediately receive the first volume and periodically during the next few months each succeeding volume in the Library will be sent automatically on approval as soon as it is published.

—I will have 30 days in which to examine the book, to pay for it if I keep it, or to return it if I decide it is not suitable for me.

—I will receive each volume I keep at a special discount price available to Charter Subscribers only. For Series 1 through 7 I'll pay $10 each instead of $12, and for Series 8 I'll pay $13 instead of $15. (If any volume does not meet my needs, I may return it postpaid without interrupting my subscription and without affecting the special price allowed to subscribers.)

—I may cancel my subscription any time.

Print Name .....
Address .....
City & Zone ..... State .....
For price & terms outside U.S.A., write McGraw-Hill Int'l, N.Y.C. FNU-9

INTERESTED IN PROCESS HEAT

in huge quantities for chemical processes? (Nuclear Reactors!)

RADIATION

as a new factor and environment for your chemical processes?

astra

offers

R & D SERVICES

for investigating possibilities, for evolving practical methods.

Send for our Nuclear Technology Folder

astra

P. O. Box 163, Milford, Connecticut

Tel. TRinity 8-2202

effective solution for shielding windows

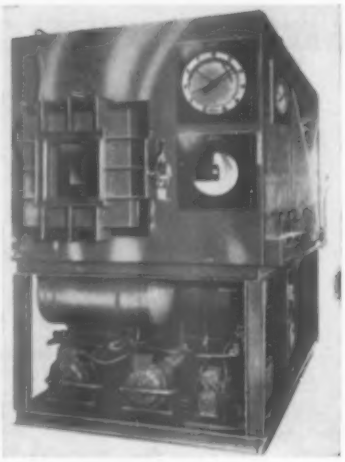
$ZnBr_2$

THE PROBLEM OF SHIELDING VIEWING WINDOWS is solved with an optical grade solution of zinc bromide. Prompt delivery of this compound, proved satisfactory and in compliance with all AEC specifications, is offered by Michigan Chemical Corporation, a quality producer of chemicals for more than 20 years.

For further information let us send you a reprint of an article from NUCLEONICS . . . "Design and Construction of Viewing Windows".

MICHIGAN CHEMICAL CORPORATION

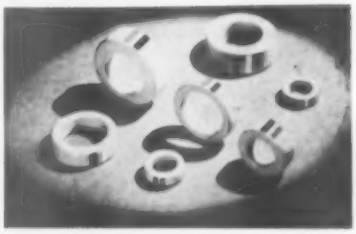
522 Bankson Street, Saint Louis, Michigan



Test Chamber

Unit shown above simulates altitudes to 150,000 ft.; has controlled temperatures from −100 to +250° F, controlled humidity at 20–95%.—Webber Manufacturing Co., 2740 Madison Ave., Indianapolis, Ind.

CIRCUIT COMPONENTS

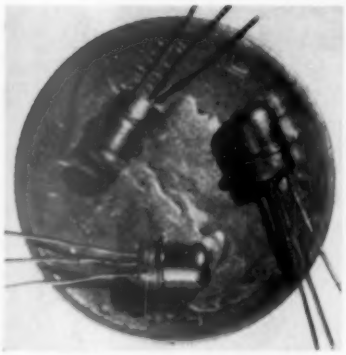


Permalloy Cores

Powder cores of molybdenum-nickel-iron formula are stock-piled and marked to indicate per cent variation from nominal inductance for 1000-turn winding.—Magnetics, Inc., Butler, Pa.

Variable Delays

Magnetostriction delay line provides delays of 1 μ sec to several millisec. Has continuously variable setting. Four pickups are supplied; more can be added.—Deltime, Inc., 608 Fayette Ave., Mamaroneck, N. Y.



Tiny Transistor

Called smallest transistor yet developed, Model M-1 operates in audio-frequency range. Device can withstand acceleration of 20,000 g.—Philco Corp., 4700 Wissahickon Ave., Phila., Pa.

PIPING COMPONENTS

Liquid-Metal Pump

High-temperature mechanical liquid-metal pump has been tested at 1,000° F for 500 hr. Rated at 150 gpm at 285-ft head. Production models of this canned-rotor pump will operate up to 1,600° F.—Westinghouse Electric Corp., 401 Liberty Ave., Pittsburgh 30, Pa.

Valves

Series 1246W stainless-steel valves are available in 0.5-in. and 1.5-in. sizes. Designed for 4,000 psi and 650 F. Self-draining.—Associated Valves & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.

Centrifugal Pumps

Two new lines of leakless general-purpose centrifugal pumps are designed for handling precious or hazardous liquids. Capable of accommodating heads to 250 ft and temperatures to 250° F—capacities to 500 gpm. Electri-Cand pump is of canned-motor type.—Allis-Chalmers Mfg. Co., Milwaukee 1, Wis.

A Growing Family of Nuclear Instruments

SCINTILLATION SPECTROMETER Model SS-2 $1375

- Improves Accuracy and Directivity
- Measures Gamma Ray Spectrum
- Excludes Scattered Radiation and Reduced Background Level

Instrument Includes:

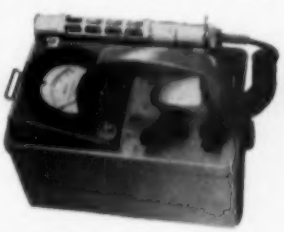
ELECTRONIC INSTRUMENTATION, Model NMS-1 ..... $685.00
Five range integrator with pre-set timer. Regulated high voltage power supply. Regulated B+ power supply.
SCINTILLATION HEAD, Model NSH-1 ..... $575.00
FOCUSING COLLIMATOR, Model NFC-1 ..... $95.00
FLAT FIELD COLLIMATOR, Model NWC-1 ..... $75.00

RADIATION MONITOR/ALARM Model RMA-3 $385.00

- Monitors and determines radiation level.
- 3-Range rate meter.
- Warning alarm at any pre-set level of radiation.
- Aural monitoring via built-in loudspeaker.

For laboratory monitoring, checking contamination, for use as laboratory rate meter, in training courses, etc.
Model RM-3 Radiation Monitor and Rate Meter without alarm feature $295.00

BETA/GAMMA SURVEY METER
Model XR-2B $179.50
Operates from plug-in batteries.
Model XR-2P $184.50
Operates from regulated electronic H.V. power supply.
Used in government hospitals throughout the country.
• Laboratory quality! • Meets rugged military requirements! • Waterproof . . . fungus proof!



Also: Scalers • Ratemeters • Survey Meters • Radiation Monitors • Ionization Chambers • Scintillation Detectors

WRITE FOR COMPLETE SPECIFICATIONS
NUCLEAR-ELECTRONICS CORPORATION
2632-36 W. Cumberland St.
Philadelphia 32, Pa., SAgamore 2-2662
FULFILLING NEEDS THROUGH CREATIVE ELECTRONICS

PROMPT DELIVERY

A GRAM
OR A CARLOAD

thorium

OXIDE
(SEVERAL GRADES)

FLUORIDE

NITRATE
AND OTHER SALTS

neutron absorbers

GADOLINIUM

SAMARIUM

EUROPIUM
AND OTHER
SEPARATED
RARE EARTHS

WRITE FOR TECHNICAL DATA

World's largest
producer of rare earth and
thorium chemicals for commercial
atomic energy use and industrial applications

LINDSAY CHEMICAL COMPANY
272 ANN STREET, WEST CHICAGO, ILL.

NEW MATERIALS

Phenol-C^{14}. Uniformly-labeled phenol-C^{14} at 1 mc/millimole is offered in 3 package sizes, 0.1–1 mc.—Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.

Lead glass. Ceria "stabilized" lead plate glass is designed for vision through shields. Specific gravity is 4.3. Available in 12 × 12 × 1-in. and 12 × 12 × 1½-in. sizes.—Pilkington Bros., Ltd., London, England.

Boral shielding. A light-weight neutron shield is sandwich containing boron carbide dispersed in aluminum in center, commercially pure aluminum on sides. Rolled plate is made ⅛ in. and ¼ in. thick.—Brooks and Perkins, 1950 W. Fort St., Detroit 16, Mich.

RADIATION DETECTORS AND ACCESSORIES

Survey Meter

For beta and gamma survey and monitoring, magnesium-cased instrument weighs only 5 lb. Full scale is 0.2, 2, or 20 mr/hr.—NRD Instrument Co., 6429 Etzel Ave., St. Louis 14, Mo.

X-Ray Survey Meter

Model 640 is designed especially for low-energy X-rays. Ranges are 10, 100, 1,000 mr/hr. Sensitive also to

FILM BADGE

Personnel Radiation Dosimeter

Mfg. by

A. M. SAMPLES MACHINE CO.
208 Tazewell Pike
Knoxville 18, Tennessee

RADIATION INSTRUMENT CO.

MODEL 412 MERCURY RELAY

PRECISION SLIDING PULSER

for Precise Calibration of Single & Multi-Channel Pulse Height Analyzers

Determines Window Widths Using Principle of *Constant Angular Velocity* — AUTOMATICALLY 10 × MORE ACCURATELY, 40 × FASTER THAN CONVENTIONAL PULSERS

Incorporates Both Manual Control and Precision Motor Drive

Simulates Pulses from Scintillation, Proportional, or Geiger Counters

RISE TIME—Less than .003 microsec.

DECAY TIME CONSTANT—1, 10, 100, 350 microsec. (selector switch).

PULSE AMPLITUDE—Continuously variable from 0 to maximum. Ranges 1, 3, 10, 30, 100, 1000 mV. Provision for direct connection of external battery for larger pulses.

POLARITY—Polarity switch permits selection of positive or negative pulses.

CALIBRATION—Self contained standard cell and null indicating balance circuit for precision adjustment.

LINEARITY—0.1% 10 turn Helical potentiometer with 5" dial.

SCAN SPEED—2 RPM standard (1, 3, 5, 6 and 10 rpm also available.)

Price $450.00 f.o.b. Silver Spring, Md.

Radiation Instrument Co.

P. O. Box 733 Silver Spring, Maryland

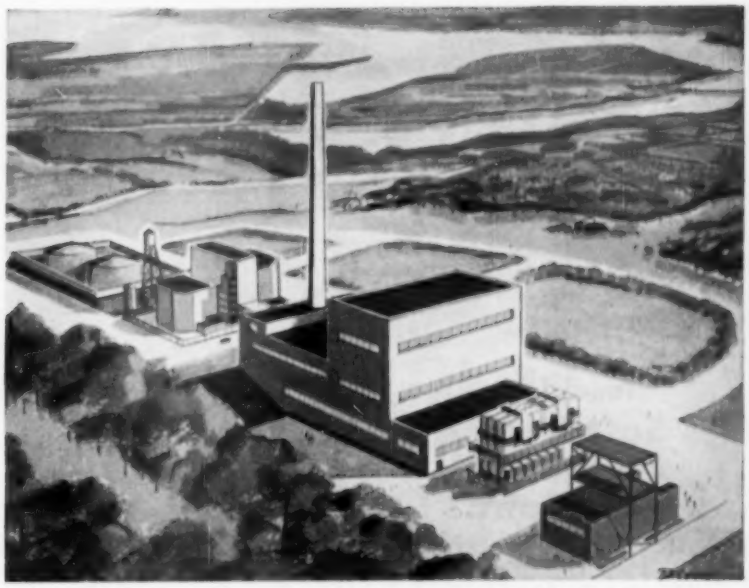
betas by virtue of Mylar window.—Victoreen Instrument Co., 3800 Perkins Ave., Cleveland, O.

Amplifier, Electrometer

Type 1230-A d-c amplifier and electrometer contains direct coupled 3-stage circuit. Open-circuit input resistance is about 10^{14} ohms. Full-scale current ranges are from 0.3×10^{-12} to 10^{-3} amp. Measures resistance from 3×10^{5} to 5×10^{14} ohms.—General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

Sensitive X-ray Counter

Flow-type proportional-counter tube No. 4 SPG with thin Mylar window (0.00025 in.) permits X-ray-diffraction analysis of low-atomic-number elements. Can be used also with millionth-inch Formvar window where zero absorption is essential.—General Electric, X-ray Dept., 4855 Electric Ave., Milwaukee 1, Wis.



Preliminary Concept of Con Edison's Nuclear Power Station

engineering the atomic age...

AN outstanding new example of Vitro Engineering Division's leadership in atomic energy is participation in Consolidated Edison's nuclear power station at Indian Point, N. Y., which has received Civilian Construction Permit #1 from the A. E. C.

Since late in 1954 Vitro Engineering has served as nuclear consultant to Con Edison. Now, as the project moves into design and construction its role has broadened:

- Vitro has been awarded the contract for general design on the non-nuclear portion of the huge complex at Indian Point.
- The Babcock & Wilcox Company, builders of the Indian Point reactor, has awarded Vitro a contract for architect-engineer services on the reactor building.

Vitro Engineering leadership in nuclear engineering is also shown by:

- Its selection as architect-engineer for Lockheed Aircraft Corporation's atomic aircraft research center at Dawsonville, Ga.
- Provision of conceptual design for two new types of research reactors for the Army Corps of Engineers at Fort Belvoir, Va.
- Preliminary design of heavy water plant for the Government of India.

The selection of Vitro to handle these key projects, and others, reflects solid performance in modern nuclear engineering design.

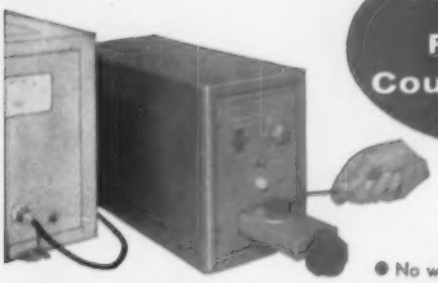
Write for detailed information to **VITRO ENGINEERING DIVISION**

Vitro

CORPORATION of AMERICA

261 Madison Ave., New York 16, N.Y.

Research, development, weapons systems
Nuclear and process engineering, design
Refinery engineering, design, construction
Uranium mining, milling, and processing
Ceramic colors, pigments, and chemicals
Recovery of rare metals and fine chemicals
Thorium, rare earths, and heavy minerals
Aircraft components and ordnance systems



THE NMC
Proportional
Counter Converter
MODEL PCC-14

Ideal for
Soft Beta
(C14, S35, Ca45)
and Alpha
(Po210, U235, Pu239)

- No window absorption
- 2 π geometry
- Full yield α counting
- Differentiates between α and β
- Negligible resolution loss
- Built-in power supply
- Converts any scaler to proportional counter
- Rapid decontamination

FREE NMC CATALOG
Covers NMC's complete line of nuclear instruments. Write today for your copy.

$485.00
F. O. B. INDIANAPOLIS

Manufacturer of the World's Finest Radiation Detection Instruments

NMC
Nuclear Measurements Corp.
2460 N. Arlington Ave. • Telephone: LIBERTY 6-2415
INDIANAPOLIS 18, INDIANA
International office: 13 E. 40th St., New York 16, N.Y.

RADIOACTIVE WASTE DISPOSAL

AEWDS offers Nuclear Laboratories a complete RADIOACTIVE WASTE COLLECTION and DISPOSAL SERVICE. This Service includes furnishing special waste containers, Pick-up service, Packaging for sea disposal and other Radiological Services.

In addition to our many services the AEWDS manufactures a portable RADIOACTIVE WASTE DISPOSAL UNIT for processing certain types of radioactive liquids.

ATOMIC ENERGY
WASTE DISPOSAL SERVICE
5410 Bond St., Oakland 1, Calif.

"AIRPURE" FILTERS

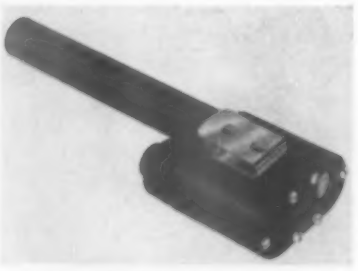
FOR REMOVAL OF RADIOACTIVE DUSTS

The basis of filter efficiency is the accuracy of the test equipment. Our testing unit is periodically compared with government equipment, assuring air filters of integrity.

No filter leaves our plant without passing rigid specifications including 99.95% efficiency on particle sizes of .3 micron as measured by dioctylphthalate smoke machine.

fmi FLANDERS MILL, INC. RIVERHEAD • NEW YORK

See you at the Show—Booth #310



Self-Charging Dosimeter

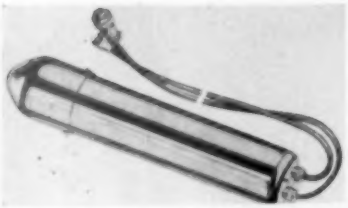
Radiac Set includes a quartz-fiber dosimeter and friction-type charger. Available in ranges from 200 mr to 600 r.—Chatham Electronics, Livingston, N. J.

Well Detector

This unit contains a well-type NaI crystal and one-tube feedback preamplifier with gain of 10 and negative output or gain of 2 and cathode follower output. Designed for gamma counting.—Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.

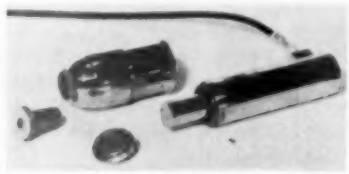
Survey Meter

Logarithmic scale makes possible direct readings of X-, gamma, and beta radiation from 3.0 to 3,000 mr/hr.—Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass.



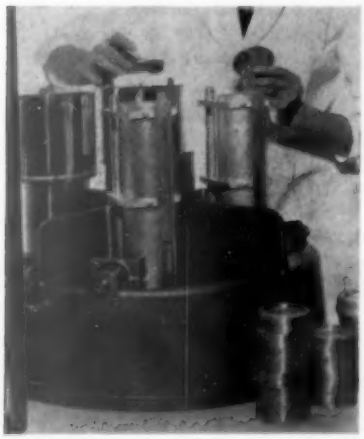
Scintillation Counter

Model DS-1A probe-type scintillation detector contains a ¾ × ¾ in. gamma-sensitive NaI crystal, 6292 photomultiplier, and a pre-amplifier circuit to permit use with ¼-volt input.—Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.



Scintillation Counter

Model SC-1U universal scintillation detector is shown with a 1 × 1-in. NaI(Tl) crystal, detachable lead shield, collimator. Provisions are made for attaching the alpha crystal (shown), beta crystals, and various sizes of gamma crystals.—N. Wood Counter Laboratory, 5491 Blackstone Ave., Chicago 15, Ill.



Two-Channel Changer

Automatic sample changer has two separate channels to permit separate assay of two types of radiation or two energies. With scaler and printer it automatically reads and prints out activity levels of up to 250 sample disks.—Beckman Instruments, 2200 Wright Ave., Richmond 3, Cal.

COLUMBIUM

High Purity

METAL POWDER and PELLETS for ALLOY ADDITION

SHIELDALLOY CORPORATION

PRODUCERS of POWDERED METALS and ALLOYS, PROCESSED MINERALS and ORES, MASTER ALLOYS, CHROMIUM METAL and other HIGH PURITY PRODUCTS

NOTE: John J. Collins, technical representative, will be at the Morrison Hotel, Chicago, to answer your inquiries during the Atomic Exposition.

SHIELDALLOY CORPORATION
WEST BOULEVARD
NEWFIELD, NEW JERSEY

NEW TOOLS

Safety — Glove — Dry Boxes of Transparent plastic or Stainless Steel as well as linear polyethylene with Atmosphere Controls including exhaust dust-fume filters and Air-Dryer systems. Available in two standard sizes: 36" x 24" x 18"; 48" x 30" x 20".

On view at the Trade Fair of the Atomic Industry

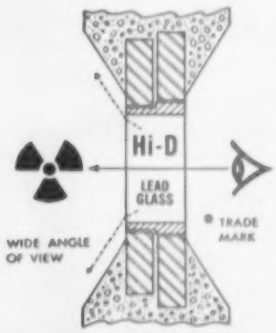
BOOTH NO. 404

P. M. LENNARD CO., INC.

P. O. Box 56, Village Station 14, N. Y.

Hi-D®

LEAD GLASS WINDOWS IN CONCRETE WALLS



Hi-D Lead Glass Windows in concrete walls are dry, and hence are completely dependable. Where the viewing problem is mainly wide-angle vision, Hi-D Glass is fully competitive in price with zinc bromide.

LARGER SIZES NOW AVAILABLE

Send for circular GS-4

PENBERTHY INSTRUMENT CO.

4501 6th AVE. SOUTH · SEATTLE 8, WASH.

SCINTILLATION PHOSPHORS

Largest selection of non-crystalline organic scintillators ever offered.

Plastic Phosphor NE 101

Available in new forms including large optical blocks up to 400 pounds weight for ultra-sensitive detectors, thin sheets for alpha and beta counting and x-ray intensification, and in small spheres and powder form. Standard size rods from 1" to 24" diameter available from stock.

New Products Now Available.

- Scintillating Gels
  For efficient internal counting of suspensions of alpha and beta emitters. Permits new techniques in scintillation counting for tracer and other applications.
- Boron, Cadmium, Gadolinium and Lead Loaded Liquid Scintillators for neutron detection, or for enhanced gamma response.
- Liquid Phosphors—In bulk form at new low prices, or encapsulated in pyrex cells with reflectors.
- Scintillation Chemicals.

We pay air shipping charges on overseas orders of plastics to anywhere in the world.

NUCLEAR ENTERPRISES LTD.

1750 Pembina Highway, WINNIPEG 9, Canada

Cable: Nuclear

British Branch: Nuclear Enterprises (G.B.) Ltd. Bankhead Medway Sighthill Edinburgh 11, Scotland.

Small Survey Meter

Radiameter is designed for health physics; operates on flashlight battery. Full-scale readings are 25 mr/hr and 1 r/hr.—Curtiss-Wright Corp., Wood-Ridge, N. J.

Portable counter. Model 522 is transistorized, operates on line current or from batteries that are automatically recharged. Includes kick-sorter.—Universal Atomic Corp., 19 E. 48th St., New York 17, N. Y.

Transistorized detectors. Counting rates to 10^6/sec, automatic countdown, optional battery-pack operation are available in scale-of-128 and decade scalers. Scintran all-transistor scintillation detectors weigh less than 7 lbs with batteries.—La Roe Instruments, PO Box 5906, Bethesda 14, Md.

LITERATURE AVAILABLE

Radiochemicals. Catalog and price list includes complete listing of firm's C^{14}, H^2, H^3 compounds.—New England Nuclear Corp., 575 Albany St., Boston, Mass.

Environmental testing. Newsletter 2-556 announces nuclear-radiation-environmental testing using Pennsylvania State swimming-pool reactor.—Inland Testing Laboratories, 1457 Diversey Pkwy., Chicago 14, Ill.

Scanning spectrometer. Recent Tracerlog describes stepwise-scanning spectrometer system.—Tracerlab, 130 High Street, Boston 10, Mass.

Research foils. Three-page letter describes foils available for radiation research.—Chromium Corp. of America, Waterbury 20, Conn.

Photomultipliers. Characteristics and uses of more than 20 photomulti-

plier tubes are described in 6-page brochure.—EMI Electronics, Ltd., Hayes, Middlesex, England.

Dag dispersions. Vol. 1, no. 2 of Dag Disperser discusses use of colloidal dispersions.—Acheson Colloids Co., Port Huron, Mich.

Radiochemicals. Ten-page price list discusses radiochemicals.—Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

Neutron monitor. Specification sheet (2 p.) describes Model-2715 Nemo for fast and thermal neutrons.—Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.

Digitizers. Bulletin BR-185 describes binary and binary-coded decimal digitizers. Illustrations, circuit diagrams, and specifications. 4 p. Bulletin BR-181 describes decimal shaft digitizers now available in 3-, 4-, 5-, and 6-decade models. Improved table of applications showing typical input and output. Describes conversion methods. 4 p.—Coleman Engineering Co., Inc., 6040 W. Jefferson Blvd., Los Angeles 16, Cal.

INDUSTRY NOTES

▶**Compagnie Francaise de Raffinage** (refining) has purchased from **High Voltage Engineering Corp.** a 2-Mv Van de Graaff accelerator for basic research in their Paris laboratories.

▶**Arthur T. Biehl** is new technical director, **Robert Mainhardt** is new general manager of **Aerojet-General Nucleonics.** Both were formerly at the University of California Radiation Laboratory.

▶**Robert E. Selff** is now director of **Cal-Rad, Inc.,** Burbank, Cal. He was formerly director of the organic synthesis division of Isotopes Specialties Co., Inc.

▶Under a $350,000 Navy allocation, **General Electric Co.** has received a contract to develop sensitive temperature, pressure, and liquid-level instruments for use in high radiation levels of atomic submarines.

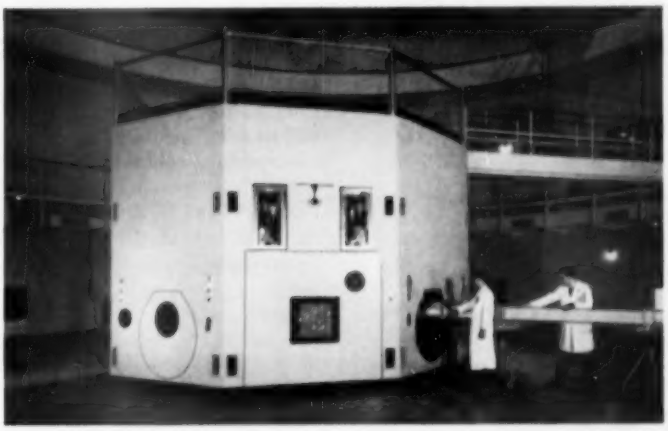
▶**Leeds and Northrup Co** has become the only instrument-making member of **Atomic Power Development Associates,** a non-profit corporation owned by 44 private companies.

▶A half interest in **Applied Radiation Corp,** Walnut Creek Cal., has been purchased by **Archer-Daniels-Midland Co.,** Minneapolis, Minn.

Have You Considered *TUBULAR* FUEL ELEMENTS?

Nested Tubular Fuel Elements Fabricated by Nuclear Metals, Inc. . . .

Vital Component of Argonne National Laboratory's CP-5 Reactor, Now in Full Operation



Tubular fuel elements — the answer to your fuel problems? An important innovation in the CP-5 Reactor, tubular elements co-extruded with integral end caps offer distinct advantages.

Nuclear Metals, Inc., fabricator of these new elements, is a pioneer in the coextrusion of nuclear fuel elements. Specialists in metallurgical research and development, the experienced staff of Nuclear Metals, Inc. can supply the research support you need.

Nuclear Metals, Inc.
Cambridge 39, Massachusetts

BIG SALE!
Replacement Human Hands

FOR MEN WHO IGNORE SAFETY REGULATIONS!

We think it is smarter to play safe. Observe all safety rules and use

Swagelok®
FITTINGS

GET ALL THE FACTS: Write for the Swagelok catalog. Address Dept. J9

CRAWFORD FITTING CO.
884 EAST 140th STREET
CLEVELAND 10, OHIO

LETTERS

E.M.I. Photomultipliers

DEAR SIR:

I have recently seen your April issue, and read with some interest the account of E.M.I. developments, by G. Morton on p. 114. Several points in this article require comment.

1. The drawing in Fig. 1: (a) is incorrect, since the slats in alternate dynodes incline in opposite directions; and (b) shows an obsolete tube, superseded over two years ago by our 6097 type.

2. Photomultipliers are produced at a branch of E.M.I. Research Laboratories at Ruislip, under the management of J. E. I. Cairns.

3. Our photosensitivity specification is not as given. Standard 6097B tubes have a guaranteed minimum of 30 μamp/lumen and an average value of 50–60 μamp/L. 6097F tubes have a guaranteed minimum of 40 μamp/L.

4. I fail to understand the comment about pulse-height statistics. The average D_1 gain in 6097 tubes is about 6, and a typical 6097B or F will give a "true" resolution of ~4% to a light pulser simulating Cs^{137}. The time resolution of any unfocussed dynode system will always be worse than that of a focussed system, and our venetian-blind system has a time spread, at half-amplitude, of 10^{-8} sec for an 11-stage tube operating at 180 volts/stage.

5. So far as I am aware, E.M.I. is the only firm in the U.K. having a Government contract for the development of photomultiplier tubes for Harwell.

—J. SHARPE
E.M.I. Research Laboratories, Ltd.
Bury Street
Ruislip, Middlesex
England

Activation Analysis

DEAR SIR:

I read with interest George W. Leddicotte's discussion on activation analysis in the May 1956 issue of NUCLEONICS (p. 46).

Table 2 on p. 47 needs revision. We have demonstrated that our 2-Mev Van de Graaff positive-ion accelerator produces a neutron flux of about 5×10^8 neutrons/sec/cm² when operated at 2 Mev, 50 microamperes, using the Be^9 reaction. This figure has been substantiated by W. H. Beamer, Dow Chemical Co., in his recent report in *Analytical Chemistry*. Incidentally, the limits of detectability of halogens he reports are closely similar to those outlined in our booklet entitled "Activation Analysis."

Our new 3-Mev model KN Van de Graaff positive-ion accelerator increases the neutron flux available to about 5×10^9 neutrons/sec/cm². Our 1-Mev model JN Van de Graaff has been operated to produce a flux of 5×10^7.

For these reasons we believe Table 2 should be revised to indicate that the range of the Van de Graaff is 10^7–10^{10} neutrons/sec/cm². As a matter of interest, we are also pursuing the feasibility of using charged particles to activate samples, thereby obtaining higher specific activations on or near the surface of the bombarded sample. This technique has provided valuable information for use in wear studies, where localized radioactivities are often desirable.

—E. ALFRED BURRILL
High Voltage Engineering Corp.
Cambridge, Mass.

EDITOR WANTED

for responsible full-time position on editorial staff of
NUCLEONICS

• NUCLEAR ENGINEER
with education or experience in reactor technology or related work. Challenging opportunity to keep in close touch with entire nuclear power field. Work with staff of technical specialists.

Send resume, salary requirements to

The Editor
NUCLEONICS
330 W. 42nd St.
New York 36, N.Y.

GAMMA SHIELDING MATERIALS

BARITE
Crushed—to specification
Ground—95% minus 325 mesh

LEAD
Powder-fineness ranges
40%-50% minus 325 mesh

IRON
Shot and Grit
Graded to specification

*

Inquiries for Metal Powders of all types solicited

METALS DISINTEGRATING COMPANY, INC.

ELIZABETH, NEW JERSEY

World's largest manufacturer of finely divided metals

Reactor Irradiation USING Pneumatic Tubes

The Airmatic Systems with a long practical history of serving as "mechanical messengers" for industrial plants and hospitals are now available for use in providing fast, safe transit of materials within the core of a nuclear reactor for irradiation. The Airmatic Systems operate on vacuum or a combination of vacuum and pressure. Power supplied by motor driven centrifugal exhauster. Rabbits of fiber, magnesium or plastic handle any type of material.

For further information, call or write:

AIRMATIC SYSTEMS, INC.
378 Bergen Blvd., Fairview, N. J.
Phone: Cliffside 6 0475

NUCLEAR CALENDAR

Sept. 20–21—Third Annual Meeting, Professional Group on Nuclear Science, IRE, Pittsburgh (*Mellon Institute*). Contact J. B. Callaghan, Westinghouse, Box 1648, Pittsburgh 30.

Sept. 25–27—Atomic Industrial Forum, annual meeting, Chicago (*Morrison*). Second annual Trade Fair of the atomic industry **Sept. 24–28**, Chicago Navy Pier. Contact D. J. Scherer, AIF, 260 Madison Ave., NYC 16.

Sept. 27—Symposium on atomic energy in economic development, International Bank for Reconstruction and Development, Washington (*Sheraton-Park*). Panel members will be Lewis L. Strauss, Sir Edwin Plowden, Sir John Cockcroft, and W. Kenneth Davis. Contact Corbin Allardice, 1818 H St. NW, Washington 25, DC.

Oct. 1–5—Seventh management course in nuclear energy, National Industrial Conference Board, New York (*Biltmore*). Contact John McMahon, NICB, 247 Park Ave., NYC.

Oct. 8—Effects of Radiation in Metals, nuclear metallurgy symposium, at AIME Institute of Metals annual meeting, Cleveland (*Carter*). Contact R. W. Shearman, AIME, 29 W 39, NYC 18.

Oct. 24–26—Symposium on radioactivity applications in petroleum research and refinery operations, Tracerlab Inc, Boston (*Statler*). Contact W. A. Stenzel, Tracerlab, 130 High St., Boston 10, Mass.

Nov. 7–9—Ninth annual conference on electrical techniques in medicine and biology (AIEE, IRE, ISA) New York (*Governor Clinton Hotel*). Will include field trips to installations of interest. Contact E. Dale Trout, General Electric Co., X-Ray Dept., Milwaukee 1.

Nov. 22–23—Symposium on Calder Hall nuclear power plant (British Nuclear Energy Conference), London. Contact A. McDonald, Sec'y, Inst. of Civil Engineers, 1–7 Great George St., London S.W.1.

Nov. 25–30—Annual meeting ASME, New York (*Statler*). Three technical sessions will be devoted to nuclear engineering. Contact B. R. Prentice, ASME, 29 W 39, NYC 18.

Nov. 26–30—Twenty-second National Power Show (ASME), New York (*Coliseum*). Will include enlarged nuclear power display section. Contact ASME, 29 W 39, NYC 18.

Dec. 10–12—Winter meeting, American Nuclear Society, Washington (*Sheraton-Park*). Besides formal meetings, there will be tours of Naval Research Lab's pool reactor, other facilities. Contact L. D. P. King, LASL, Box 1663, Los Alamos, N. M.

Sudden Light!

This cluster of flashbulbs throws sudden light on a problem that has occupied scientists for many years: the effect of weather on the transmission of electromagnetic radiation through the atmosphere. Technical Operations' scientists have developed unique theoretical and experimental techniques to solve this and many other problems. Association with Technical Operations can throw an equally sudden light . . .

on your career as a

Physicist or Mathematician

Technical Operations is working on a wide range of problems involving physicists and mathematicians—in reactor development, experimental design, nuclear weapons effects, microwaves, digital computing, operations research. Positions are available at Arlington, Mass., and Washington, D. C.

With These Advantages:

- simple, sensible salary policies
- management by scientists
- opportunities for fundamental research in a variety of fields
- an organization small enough for individual recognition, large enough for long-range security

Write for brochure and short application form.

Robert L. Koller

TECHNICAL OPERATIONS
INCORPORATED
6 Schouler Court
Arlington 74, Massachusetts

WHERE TO BUY

Rapid—Reliable

NATION-WIDE NUCOR FILM BADGE SERVICE

for industrial and medical personnel protection

Available from these subsidiaries of

NUCLEAR CORPORATION OF AMERICA, INC.

In the East:
Nuclear Consultants, Inc.
3361 Crescent Street
Long Island City 6, N. Y.

In the Mid-West:
Nuclear Consultant, Inc.
9842 Manchester Road
St. Louis 19, Mo.

In the West:
Isotopes Specialties Company, Inc.
703 S. Main Street
Burbank, California

FOR SALE

3.3 DENSITY NON-BROWNING GLASS BLOCKS

Random sizes up to 12" x 32" and 4" to 6" in thickness. With or without 1" steel frames.

Suitable for low intensity gamma protection. Coefficient of linear absorption—.190 per cm thickness at 1.3 mev (Cobalt 60).

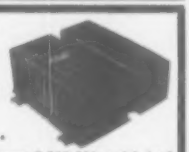
Details and prices upon request.

R. V. HARTY COMPANY, INC.
1433 Sloman Ave.,
Detroit 11, Michigan

SEARCHLIGHT SECTION

SOLA CONSTANT-VOLTAGE TRANSFORMER

Ends fluctuating line voltage!



OVER 60% OFF...

the factory price at a 1-input 2,000 VA unit! And here's another bonus! This Air Forces 2,000 VA overstock, Sola Cat. No. 30768, has 4 inputs! 90-125 V., 190-250 V., 60 cy. or 50 cy. Isolated secondary is constant 115.0 V. ±1% from no load to full-load of 17.4 amp. So, if you choose, use it as a 220:115 V. step-down. And slash $147.50 off the factory 1-input price!

Brand new in original wood box. 4 cu. ft. Ship. wt. 254 lbs. F.O.B. Pasco, Wash. Only **$97.50**

(EXPORTERS: Note choice of 50 cycles.)

THE M. R. COMPANY
P. O. Box 1220-D Beverly Hills, Calif.

PROFESSIONAL SERVICES

HEALTH PHYSICS SERVICES, INC.
1111 Low Street Baltimore 2, Maryland

Announces

1. Beta, Gamma, and Neutron Film Badge Service—a reliable, discriminate, permanent method of monitoring your radiation exposures.
2. Other radiation monitoring services and consultations

TO MEET *YOUR* NEEDS
WRITE FOR OUR BROCHURE

NEWSMAKERS

Sir Jack Stevens has retired as chairman of the Australian Atomic Energy Commission. He will succeed **Viscount Chandos** as chairman of Australian Electrical Industries Ltd. and will also be chairman of the firm's operating subsidiary. No new chairman has been appointed yet to head Australia's AEC.

Walter Kidde Nuclear Laboratories has named **William P. Senett** head of its laboratory research department, and **Frederick A. Zenz** senior engineer. Senett, a veteran of the Manhattan District where he worked on diffusion membrane research for uranium isotope separation, comes to Walter Kidde from a germanium solid-state research study at RCA. Zenz was development engineer at M. W. Kellogg, working on fluidized reactor design.

John B. Giacobbe, formerly plant metallurgist for Superior Tube Co., Norristown, Pa., has been appointed director of Superior's newly-created nuclear products division, and will be responsible for all its operations.

Frederick G. Stroke has been named manager of operations in charge of engineering development and sales in the nuclear field at Bettinger Corp., Waltham, Mass., a specialist in ceramic coatin applications, including nuclear equipment hot parts.

Robert N. Brey has been promoted to supervisor of nuclear systems at Leeds & Northrup's Market Development division. With L&N since 1946, he is a member of the firm's nuclear program committee.

Philip Gill, formerly assistant director of the radiological service of the state of California, has joined the staff of Isotopes Specialities Co., Burbank, Calif.

In an effort to increase efficiency of its Hanford operation, General Electric has carried out a major staff reorganization tending toward decentralization. Under the new plan, there will be three product departments plus three supporting organizations and counsel. Each component will be as nearly like an independent business as over-all Hanford interests will permit. Each manager will be closer to the actual work for which he is responsible, in accordance with GE management philosophy holding that organization components should be so devised that a manager with wide authority for making decisions should have an organization small enough for one man "to get his arms around." The reorganization will not materially affect the total number of employees at Hanford—about 9,300, nor the dollar value of the plant payroll—about $55-million. The old Hanford organization was centralized, with all three manufacturing operations in one group, and other groups provided engineering, finance, personnel, and other functions for all of Hanford. The new department under the name "irradiation processing" handles operation of the eight plutonium-producing reactors. The new components and the men named to head them are shown on the chart on the facing page.

EMPLOYMENT OPPORTUNITIES

The Advertisements in this section include all employment opportunities—executive, management, technical, selling, office, skilled, manual, etc.

Positions Vacant	Selling Opportunities Offered
Positions Wanted	
Part Time Work	Employment Agencies
Civil Service Opportunities	Employment Services
Selling Opportunities Wanted	Labor Bureaus

RATES

DISPLAYED: The advertising rate is $15.00 per inch for all advertising appearing on other than a contract basis. Contract rates quoted on request.

An advertising inch is measured ¼" vertically on a column—3 columns—30 inches to a page.

Subject to Agency Commission.

UNDISPLAYED: $1.50 per line, minimum 3 lines. To figure payment count 5 average words as a line.

Position Wanted ads are ½ of above rate. Box Numbers—counts as 1 line.

Discount of 10% if full payment is made in advance for 4 consecutive insertions.

Not subject to Agency Commission.

Send NEW ADS or Inquiries to Classified Adv. Div. of NUCLEONICS, P.O. Box 12, N. Y. 36, N. Y.

REPLIES (Box No.): Address to office nearest you c/o this publication, Classified Adv. Div.
NEW YORK: P. O. Box 12 (36)
CHICAGO: 520 N. Michigan Ave. (11)
SAN FRANCISCO: 68 Post St. (4)

Position Wanted

Physicist, M.S., 6 years research and administrative experience. Familiar with radioisotope work including dosimetry, counting equipment and techniques, medical applications, AEC licensing procedures. Desire position in Chicago area. PW 2725, Nucleonics.

Engineer, ME, EE

Nuclear Reactor Design for Aircraft

A long-range well-paid career position in the highly promising new field of aircraft nuclear propulsion, is now open with General Electric. This position will appear to the qualified engineer whose creative fluency keeps him abreast of the many unusual design problems that he will encounter.

Requirements include a B.S. or advanced degree in mechanical or electrical engineering, plus familiarity with fluid flow, heat transfer, stress, etc. Some knowledge of fabrication processes and techniques is preferable.

Publication of research results in the appropriate classified or open literature is encouraged.

Openings at Cincinnati, Ohio and Idaho Falls, Idaho

Address replies, stating salary requirements, to location you prefer.

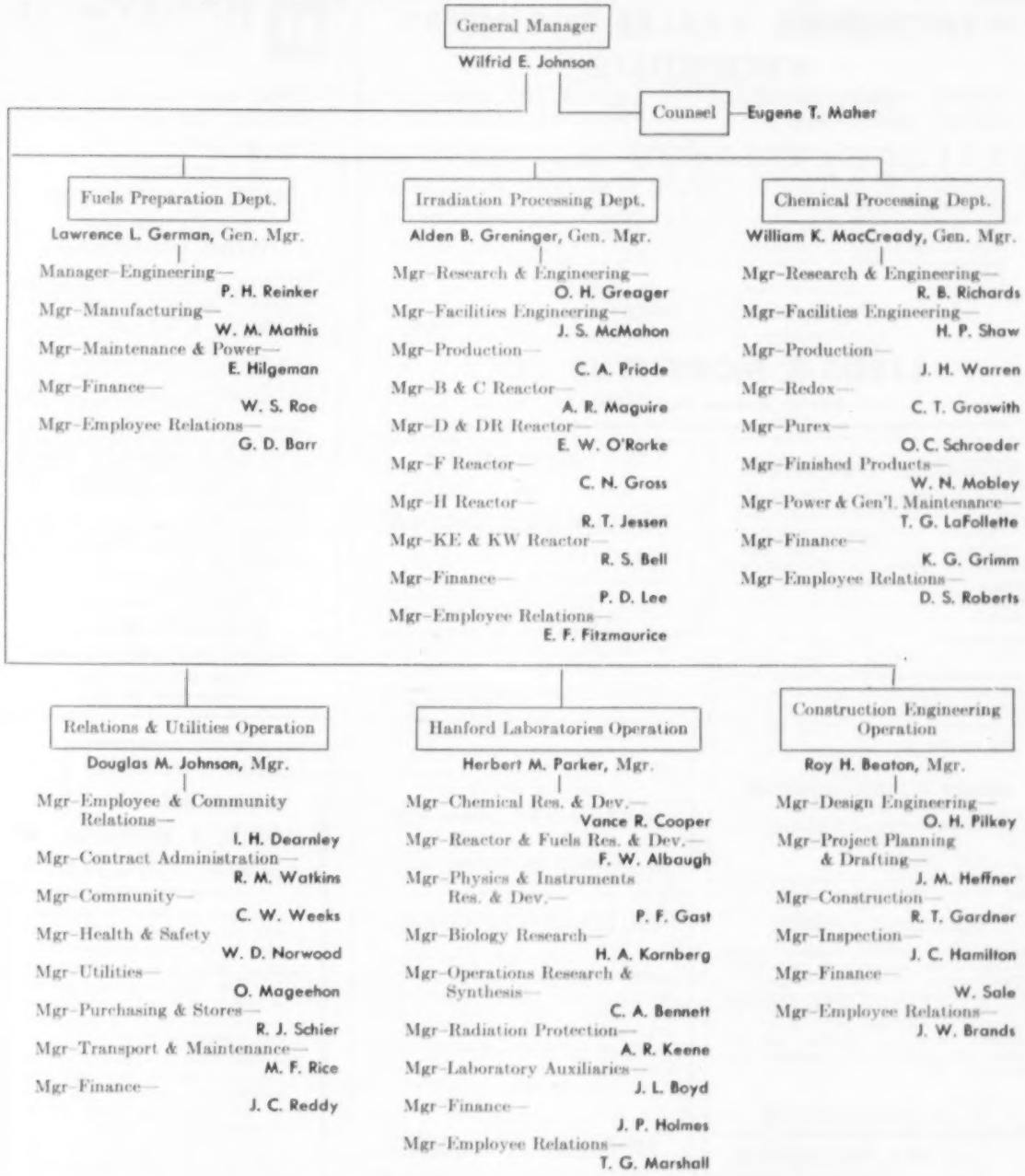
J. R. Rosselot
P. O. Box 132
Cincinnati, O.

L. A. Munther
P. O. Box 535
Idaho Falls, Idaho

GENERAL ELECTRIC

Additional Employment Opportunity Advertising on pages 182–186

New Hanford Organizational Chart


General Manager
Wilfrid E. Johnson
Counsel
Eugene T. Maher
Fuels Preparation Dept.
Lawrence L. German, Gen. Mgr.
Manager–Engineering— P. H. Reinker
Mgr–Manufacturing— W. M. Mathis
Mgr–Maintenance & Power— E. Hilgeman
Mgr–Finance— W. S. Roe
Mgr–Employee Relations— G. D. Barr
Irradiation Processing Dept.
Alden B. Greninger, Gen. Mgr.
Mgr–Research & Engineering— O. H. Greager
Mgr–Facilities Engineering— J. S. McMahon
Mgr–Production— C. A. Priode
Mgr–B & C Reactor— A. R. Maguire
Mgr–D & DR Reactor— E. W. O'Rorke
Mgr–F Reactor— C. N. Gross
Mgr–H Reactor— R. T. Jessen
Mgr–KE & KW Reactor— R. S. Bell
Mgr–Finance— P. D. Lee
Mgr–Employee Relations— E. F. Fitzmaurice
Chemical Processing Dept.
William K. MacCready, Gen. Mgr.
Mgr–Research & Engineering— R. B. Richards
Mgr–Facilities Engineering— H. P. Shaw
Mgr–Production— J. H. Warren
Mgr–Redox— C. T. Groswith
Mgr–Purex— O. C. Schroeder
Mgr–Finished Products— W. N. Mobley
Mgr–Power & Gen'l. Maintenance— T. G. LaFollette
Mgr–Finance— K. G. Grimm
Mgr–Employee Relations— D. S. Roberts
Relations & Utilities Operation
Douglas M. Johnson, Mgr.
Mgr–Employee & Community Relations— I. H. Dearnley
Mgr–Contract Administration— R. M. Watkins
Mgr–Community— C. W. Weeks
Mgr–Health & Safety W. D. Norwood
Mgr–Utilities— O. Mageehon
Mgr–Purchasing & Stores— R. J. Schier
Mgr–Transport & Maintenance— M. F. Rice
Mgr–Finance— J. C. Reddy
Hanford Laboratories Operation
Herbert M. Parker, Mgr.
Mgr–Chemical Res. & Dev.— Vance R. Cooper
Mgr–Reactor & Fuels Res. & Dev.— F. W. Albaugh
Mgr–Physics & Instruments Res. & Dev.— P. F. Gast
Mgr–Biology Research— H. A. Kornberg
Mgr–Operations Research & Synthesis— C. A. Bennett
Mgr–Radiation Protection— A. R. Keene
Mgr–Laboratory Auxiliaries— J. L. Boyd
Mgr–Finance— J. P. Holmes
Mgr–Employee Relations— T. G. Marshall
Construction Engineering Operation
Roy H. Beaton, Mgr.
Mgr–Design Engineering— O. H. Pilkey
Mgr–Project Planning & Drafting— J. M. Heffner
Mgr–Construction— R. T. Gardner
Mgr–Inspection— J. C. Hamilton
Mgr–Finance— W. Sale
Mgr–Employee Relations— J. W. Brands

NUCLEONICS BUYERS' GUIDE

. . . in the November issue

The industry's source of buying information

for nuclear components, end products and services

atomic

★ ENGINEERS ★ SALES ENGINEERS ★ SCIENTISTS

NUCLEAR INSTRUMENTATION — *MARKET DEVELOPMENT*
RESEARCH-DEVELOPMENT — *INDUSTRIAL APPLICATION*

Our E-X-P-A-N-D-I-N-G program in the Nucleonics Field offers exceptional opportunities for engineers, sales engineers and scientists in nuclear instrumentation.

The men we have in mind should have advanced degrees in Electrical Engineering, Mechanical Engineering, Chemical Engineering or Physics and have a strong knowledge of basic principles of nuclear reaction. 2 to 10 years experience in magnetic and electronic circuitry, particularly as applied to servo-mechanisms, control and measurement techniques with emphasis on principles of radiation detection and control.

Interviews will be held in Chicago during week of Sept. 23 through Sept. 28. Appointment can be arranged at our Exhibit Booth # 203 at the Trade Fair of the Atomic Industry.

If inconvenient, send your resume to—

MR. WAYNE L. BESSELMAN
Coordinator of Technical Employment

LEEDS & NORTHRUP CO.

4901 Stenton Avenue, Philadelphia 44, Pa.

HONEYWELL
'FIRST IN CONTROLS'

OFFERS Broad Opportunities in the NUCLEAR FIELD for ENGINEERS with experience in—

RESEARCH
DESIGN and DEVELOPMENT
APPLICATION and SYSTEMS ENGINEERING

Openings for ELECTRICAL ENGINEERS, MECHANICAL ENGINEERS, PHYSICS MAJORS in all phases of Industrial Instrumentation, including Automatic Data Processing and Nuclear Reactor Controls.

Opportunities permit designing and working with equipment from the initial ordering through development to actual operational checkout. These positions offer excellent potential for men with ambition and inventiveness.

Openings are with a separately functioning division which is expanding rapidly to meet present trend in Automatic Data Processing and Reactor Control areas. Positions provide prestige and benefits offered by one of the leaders in INDUSTRIAL AUTOMATION.

Send a complete resume of your education, experience and special training as well as a statement of your interest and salary requirements to:

D. R. GARVEY
Manager of Employment

HONEYWELL
BROWN INSTRUMENTS DIV.
Wayne & Windrim Aves.
Philadelphia 44, Pa.

RESEARCH ENGINEERS

Unusual opportunity to do stimulating work in Chemical Engineering or Reactor Technology research on pilot plant or laboratory scale. Several years experience desirable in reactor water technology, reactor economics, or radiochemical techniques.

Opportunities to direct projects or work under experienced men. These are permanent positions offering professional and personal growth. Excellent employee benefits including tuition-free graduate study. Please send resume to:

Mr. J. A. Metzger
ARMOUR RESEARCH FOUNDATION
of
Illinois Institute of Technology
10 West 35th Street
Chicago, Illinois

RESEARCH IN NUCLEAR WELL LOGGING

* * *

Nuclear Physicist, Ph.D. or equivalent, preferably with some experience in oil well logging or geology. Principal emphasis in this position will be placed on development and interpretation of new methods.

- Position is permanent
- New facilities—suburban location
- Excellent working conditions
- Excellent advancement opportunities
- Liberal publication policy
- Salary open

Apply in writing to:

Gulf Research & Development Co.
P. O. Drawer 2038
Pittsburgh 30, Pennsylvania

SENIOR POSITIONS AVAILABLE AT JACKSON & MORELAND, INC. BOSTON, MASSACHUSETTS

Two senior positions for engineers with nuclear experience are now open in this long-established firm.

Systems Engineer—responsible for heat balance calculations, design of piping and auxiliary systems, and for consultation on instruments and controls.

Shielding Engineer—responsible for shielding design and radiation protection of component parts, and for consultation on health physics instrumentation.

These positions are in connection with projects involving reactors, particle accelerators and hot laboratories.

Employee benefits include pension and profit sharing plans.

Write at once to: Mr. P. Compagnone
JACKSON & MORELAND, INC.
600 Park Sq. Bldg., Boston 16, Mass.

ELECTRONIC DESIGNER

Development and design of industrial measurement and control equipment for the continual process industries. Unusual opportunities in a rapidly expanding firm and industry for personal growth through technical "know how" and hard work. BSEE or MSEE required. 1 to 10 years' experience. Servo and feedback experience helpful. Send resume to: 1205 Chesapeake Ave., Columbus 12, Ohio.

Industrial Nucleonics CORPORATION

NUCLEAR PERSONNEL

The only organization of its kind devoted solely to the *placement* of technical and administrative personnel in the nuclear energy industry. Contact with over 600 firms by a graduate technical staff assures selective placement. No fees. For information send name and address to:

Director
NUCLEAR PERSONNEL
30 N. La Salle St. Chicago 2, Ill.

ASSISTANT SECTION HEADS AND SUPERVISORY ENGINEERS

Opportunities available in our Reactor Engineering Department on the San Francisco Peninsula of California. Require Power or Research Reactor System experience.

Please mail complete chronological experience record, including education, salary history, etc. *All replies strictly confidential.*

AMERICAN-STANDARD ATOMIC ENERGY DIVISION
1682 Broadway **Redwood City, Calif.**

New Advertisements
received by September 12th will appear in October issue, subject to space limitations.

Address copy to the Classified Advertising Division
Nucleonics
P. O. Box 12 New York 36, N. Y.

The First in a Series of Announcements on Progressive Expansion of Program and Facilities in Mathematics at the Knolls Atomic Power Laboratory:

GENERAL ELECTRIC'S
KNOLLS ATOMIC POWER LABORATORY

Announces

CONSTRUCTION OF A MODERN CENTER FOR MATHEMATICS

Because we believe that theory is our most powerful weapon in dealing with reality, we are expanding our Mathematical Analysis Program. One of the first elements in this expansion is the creation of a new and modern building for mathematicians and physicists, which will be the center of the Laboratory's efforts to meet by theoretical means the challenges of the nuclear energy field.

We are seeking men with strong mathematical training at all degree levels to participate in this expanding Numerical Analysis Program—a program growing not only in staff, equipment, and facilities, but also in concept and function. They will work in close association with our theoretical and experimental physicists. There are openings in each of the following fields:

RESEARCH IN MATHEMATICAL TECHNIQUES

Numerical solution of the diffusion equation for complicated geometrical arrays taxes even the most powerful electronic computers. Fundamental work in iterative techniques must be carried out.

FORMULATION AND EVALUATION OF THEORIES

Due to the nature of physical situations now being encountered, the rough approximations which were formerly adequate must now be improved. The ultimate test of such improvement is comparison with experiment.

APPLICATIONS TO REACTOR PROBLEMS

A broad program of computational tools for reactor design must be effected incorporating the best available techniques. Strong interests in computation and in machine properties are indicated. The program at Knolls offers the atmosphere, the equipment, the richness of subject matter and the material benefits conducive to a satisfying career in applications of mathematics.

A LETTER TO DR. S. R. ACKER, EXPRESSING YOUR INTEREST, WILL RECEIVE IMMEDIATE ATTENTION.

Knolls Atomic Power Laboratory

GENERAL ELECTRIC

SCHENECTADY, N. Y.

REACTORS–
CRITICAL FACILITIES

NATIONAL REACTOR TESTING STATION

Phillips Petroleum Company's expanding reactor program at the National Reactor Testing Station, Idaho Falls, Idaho, will shortly include seven reactors. Career opportunities exist in reactor physics and reactor engineering. Challenging problems in reactor theory and design, kinetic behavior of reactors, numerical analysis, heat transfer, stress analysis, and radiation damage are being offered to above-average technical men.

Provisions will be made to give course work and on-the-job training in reactor physics to inexperienced men with advanced background in mathematics and physics who desire to work in reactor physics.

Idaho is unrivalled as a center for outdoor recreation in an area free from metropolitan congestion. Idaho Falls, where 90% of our 1100 employees in the Division live is a fine progressive city of 25,000 population. Its schools and other cultural facilities to meet family needs are well above average.

For further details direct your inquiries to:

PHILLIPS PETROLEUM COMPANY

P. O. Box 1259 Idaho Falls, Ida.

ENGINEERS . . .

Control Systems

Research and Development for AIRCRAFT NUCLEAR PROPULSION

Exceptional opportunities are now available in this General Electric Department for control systems engineers who want to be in the lead in their art. You can't be further ahead than the development of control systems for aircraft nuclear power plants. You can't find greater scope than this group charged with executing complete projects—from idea through research and development to testing.

OPENINGS EXIST AT VARIOUS LEVELS IN:

- **Systems Analysis**
- **Servomechanisms**
- **Systems Applications**
- **Printed Circuits**
- **Environmental Testing**
- **Saturable Core Components**

at Cincinnati, Ohio and Idaho Falls, Idaho

In addition to these professional advantages, you'll enjoy the many personal benefits that go with being part of General Electric.

Send reply in confidence, stating salary requirements, to location you prefer.

Mr. J. R. Rosselot
P. O. Box 132
Cincinnati, Ohio

Mr. L. A. Munther
P. O. Box 535
Idaho Falls, Idaho

GENERAL ELECTRIC

ELECTRONICS ENGINEERS

ARE YOU INTERESTED IN MILLI-MICROSECOND TECHNIQUES AS USED IN BASIC NUCLEAR INSTRUMENTATION?

WRITE US IF YOU HAVE THE FOLLOWING QUALIFICATIONS:

A desire to participate in the expanding electronic instrument development program of one of the foremost university nuclear research laboratories. . . .

Ability & experience in the design & analysis of basic pulse circuits, such as the multivibrators, univibrators, blocking oscillators, etc. & in the design of regulated power supplies, feedback amplifiers & other self-regulating electronic devices. . . .

P2673 NUCLEONICS
Class. Ad. Div. P.O. Box 12, N.Y. 36, N.Y.

OUTSTANDING OPPORTUNITIES in AIRCRAFT NUCLEAR PROPULSION

Are Now Available at The BUDD CO. in PHILADELPHIA

Our new long range program has created challenging and responsible positions in our nuclear engineering division for men with some experience and seeking advancement in the following groups:

MECHANICAL ENGINEERS

For Structural Analysis

MECHANICAL DESIGN ENGINEERS

Thermodynamic Analysts

PROJECT ENGINEERS

Mechanical Background

Salaries Commensurate With Experience

Call or write for personal and confidential interview or mail a complete resume to—

The BUDD Company
Employment Service Dept.
2450 Hunting Park Avenue
Philadelphia 32, Pa.

the challenge of the unknown

Watch the sky!

Within months, Martin will open a new chapter in world history with the launching of the first of a series of earth satellites.

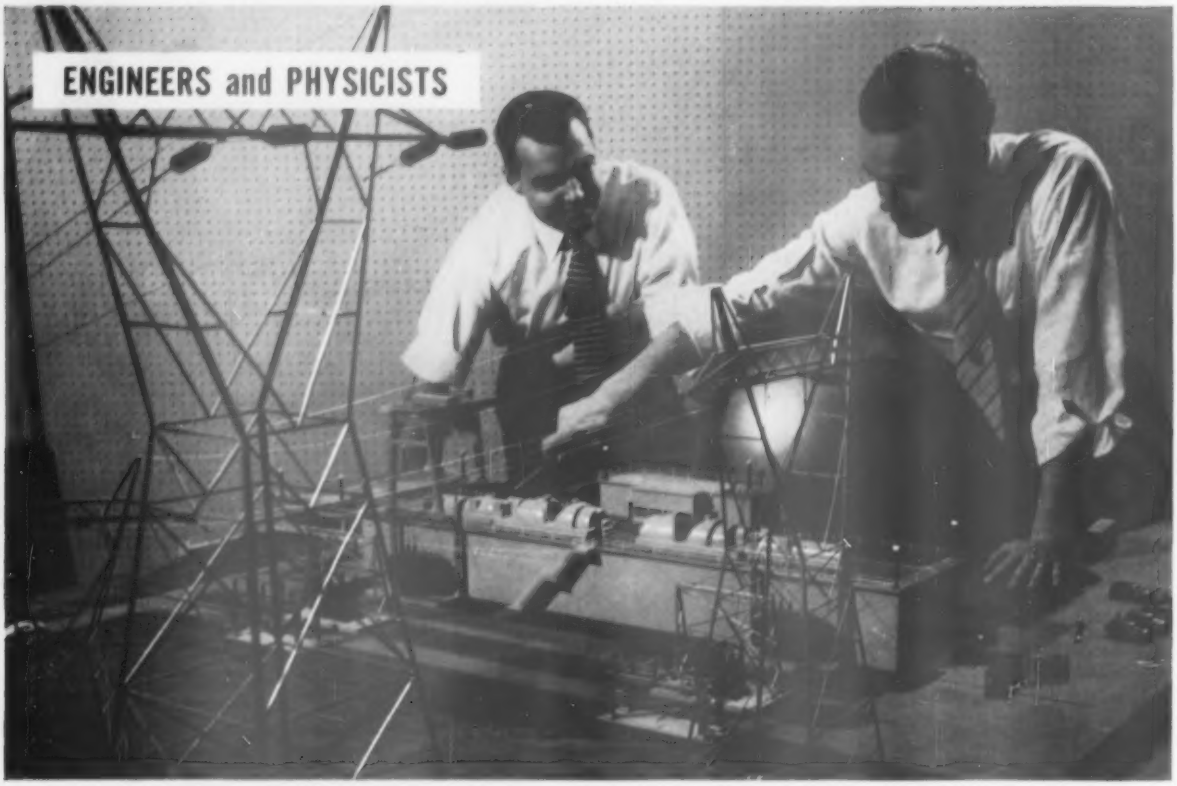
If you are interested in the challenge of the unknown, remember this:

No other engineering group in the world will learn more, *sooner*, about this final frontier of scientific exploration.

If you think you'd like to go along, contact J. M. Hollyday, Dept. N-09, The Martin Company, Baltimore 3, Maryland.

MR. ROLAND HOOD, our representative, will be at the MORRISON HOTEL, CHICAGO, during the TRADE FAIR OF THE ATOMIC INDUSTRY.

MARTIN



General Electric Now Offers More Career Opportunities In Commercial Atomic Power

By 1980 it is estimated that 67% of all new industries will be powered by nuclear energy.

Rapid developments in General Electric's Atomic Power Equipment Department require high-caliber men to work on commercial applications of atomic power: reactors to provide light and power for a major city, and others designed for industrial testing and medical research. Also for development of reactor components, fuel elements and control systems.

Look into the career possibilities with General Electric...the company with the greatest amount of experience in more phases of atomic development.

OPENINGS AT ALL LEVELS IN:
Special and Power Reactor Design • Engineering and Nuclear Physics • Power Plant Design • Control and Instrumentation • Fuel Element Development • Coolant Chemistry • Applied Mechanics • Remote Handling Facilities • Structures • Product Development

While at the Trade Fair of the Atomic Industry in Chicago, call Mr. J. R. Rosselot, Sheraton Hotel (MIchigan 2-9459) September 24 thru 28, for details about opportunities in commercial atomic power at General Electric.

Send resume in confidence to:

ATOMIC POWER EQUIPMENT DEPARTMENT

GENERAL ELECTRIC

2155 South First Street • San Jose, California

INDEX TO ADVERTISERS

SEPTEMBER 1956

A C F Industries, Inc. 20
A M F Atomics, Inc. 43
Acoustica Associates, Inc. 49
Aerojet-General Nucleonics 27
Airmatic Systems, Inc. 179
Allied Radio Corp. 166
Ameray Corp. 125
Anton Electronic Laboratories, Inc. . 161
Applied Radiation Corp. 13
Astra 170
Atomic Energy Waste Disposal Service 174
Atomics International a division of North American Aviation, Inc. . . . 46
158
Babcock & Wilcox Co. 10, 11
Baird Associates-Atomic Instrument 3rd Cover
Barnstead Still & Demineralizer Co. . 120
Bar-Ray Products, Inc. 44
Beach-Russ Co. 116
Blickman, Inc., S. 3
Borg-Warner Corp. 33
Byron Jackson Pumps, Inc., a sub. of Borg-Warner Corp. 34
Carlson, Inc., G. O. 19
Central Research Laboratories, Inc. . 123
Central Scientific Co. 52
Century Electronics & Instruments, Inc. 135
Chatham Electronics Div. of the Gera Corp. 128
Cohn Mfg. Co., Inc., Sigmund 160
Columbia University Press 130
Communication Accessories Co. 152
Consolidated Electrodynamics Corp., Rochester Div. 42
Convair-Fort Worth 142
Corning Glass Works 155
Crane Co. 28
Crane Packing Company 117
Crawford Fitting Co. 178
Crossroads Marine Disposal Corp. . . 167
Daystrom, Inc. 6, 7
Detectolab, Inc., affiliate of Borg-Warner Corp. 35
Dian Laboratories, Inc. 29
Eberline Instrument Division of Reynolds Electrical & Engineering Co., Inc. 139
Ekco Electronics, Ltd. 188
Electronic Associates, Inc. 137
Elliott Brothers (London) Ltd. 133
Fairchild Camera & Instrument Corp. 121
Flanders Mill, Inc. 174
Ford Instrument Co., Div. of Sperry Rand Corp. 113
Foster Wheeler Corp. 15
General Electric Co. 4, 5
50
General Mills, Mechanical Div. 157
General Regulator Corp. 145
Hamner Electronics Co., Inc. 166
Harshaw Chemical Co., The 37
Harty Co., Inc., R. V. 180
Hastings-Raydist, Inc. 167
High Voltage Engineering Corp. . . . 115
Instrumentation Associates 164
International Nickel Co., Inc. 9
International Resistance Co. . . 2nd cover
Ionics, Inc. 168
Jarrell-Ash Co. 148
Jordan Electronics, Inc. 163
Kaiser Engineers, Nuclear Engineering Division 111
Kelley & Co., O. G. 8
Kidde Nuclear Laboratories, Inc., Walter 118
Kinetics Corp. 164
Kinney Mfg. Div., The New York Air Brake Co. 143
Kollmorgen Optical Corp. 159
L-O-F Glass Fibers Co. 26
Landauer Jr. & Co., R. S. 157
Leeds & Northrup Co. 48

Radiation Applications Incorporated

offers its experienced team of Associates and staff to assist in the development of profitable products and processes utilizing radiation.

CONSULTATION—in radiation processing, design of radiation facilities, process control, nuclear chemistry and related problems on either a per diem, fee, or retainer basis.

DOSIMETRY SERVICE—a complete commercial service for the precise measurement of high level doses of alpha, electron, and gamma radiation. Dosage: 200,000–10,000,000 roentgens. Calibration service. Price list on request.

PUBLICATION—our monthly technical review, **Radiation Applications**, surveys and comments upon such fields as Radiation Chemistry, Source Technology, Dosimetry, Waste Disposal, Instrumentation and the significance of radiation to specific industries such as Oil, Polymer, Food, Drug and Pharmaceutical. Available on a subscription basis. Sample copy on request.

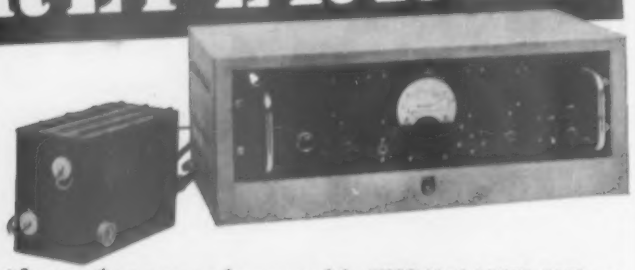
RADIATION SERVICE—arrangements can now be made for convenient and confidential irradiation services performed under expert supervision at RAI's Industrial Radiation Center.

We invite your inquiries

DR. V. LAWRENCE PARSEGIAN
DR. ELMER L. GADEN, JR.
MR. BERNARD MANOWITZ
DR. W. RALPH SINGLETON
DR. JOSEPH S. BUTTS
DR. ERNEST J. HENLEY
MR. EDWARD SARGENT
DR. JOSEPH SILVERMAN—TECHNICAL DIRECTOR

RADIATION APPLICATIONS INCORPORATED
342 Madison Avenue • New York 17, N. Y. • Oxford 7-3797

PREFERRED



During the past 5 years, the proven performance of the EKCO Model 1079-C Vibrating Reed Electrometer has made it preferred by actual users, both here and abroad.

Low in cost, compact, rugged and easily serviced; its high, full-scale sensitivity and inherent stability makes the EKCO Model 1079-C ideal for all applications involving small current and voltage measurements.

STABILITY:..... ± 1 mv, day-to-day.
SENSITIVITY:.....0.03 μμa full-scale reading @ max.
RANGES:.....0-30, 0-100, 0-300, 0-1000 mv.
INPUT:.....Internal, switch-controlled, 10^{9}, 10^{10}, 10^{12} ohm resistors.
OUTPUT:.....Operates with 1 ma or 100 mv recorder.
POWER:.....110/120 or 200/250 v, 40/60 cps, 40 w.
WEIGHT:.....Only 29 lbs., complete with cables.

Write TODAY for Bulletin L-572 for complete data

AMERICAN TRADAIR CORP.
34-01 30th Street, Long Island City 6, N. Y. • Dept.
U.S. SALES & SERVICE for
EKCO ELECTRONICS, LTD., Essex England

NEW ENGLAND NUCLEAR RADIOACTIVE COMPOUNDS

	Price/mc	Min. order/mc
• GLYCINE-1-C^{14}	$245	0.1
• GLYCINE-2-C^{14}	300	0.1
• METHYL-C^{14} IODIDE	175	0.5
• SODIUM ACETATE-1-C^{14}	85	0.5
• SODIUM ACETATE-2-C^{14}	185	0.5
• SODIUM FORMATE-C^{14}	95	0.5

WRITE FOR RADIOCHEMICAL CATALOG

DELIVERY FROM STOCK

new england nuclear corp.
575 ALBANY STREET, BOSTON 18.

DO YOU HAVE A RADIOACTIVE WASTE DISPOSAL PROBLEM?

Radiological Can Solve It

Radiological Service Co. maintains a pick-up service for safely removing radioactive wastes. For isotope users beyond pick-up area a convenient shipping service is available. Service meets all A.E.C. recommendations.

Waste Disposal Service Performed Since 1952 for Leading Labs Throughout U. S.

WRITE FOR COMPLETE DETAILS AND PRICES

Radiological Service Company, Inc.

28-22B ASTORIA BLVD. LONG ISLAND CITY 2, N. Y.

Lennard Co., P. M.....176
Linde Air Products Co.....160
Lindsay Chemical Co.....172
Lithium Corp. of America, Inc.....14
Lockheed Missile Systems, Div.....127
Los Alamos Scientific Laboratory...25
Martin Co., Glenn L.....109
Marvel-Schebler Products Div. of Borg-Warner Corp.....36
Maywood Chemical Works.....122
McGraw-Hill Book Co.....128, 169
Metal & Controls Corp., Nuclear Products Div.....40
Metals Disintegrating Co., Inc.....179
Mettler Instrument Corp.....38
Michigan Chemical Corp.....170
Microdot Div. of Felts Corp.....157
Minneapolis-Honeywell Regulator Co., Industrial Div.....4th Cover
Nash and Thompson Ltd.....124
National Lead Co.....12
National Radiac, Inc.....164
National Research Corp.....39
New England Nuclear Corp.....188
Nuclear Corp. of America, Inc.....180
Nuclear Development Corp. of America.....16
Nuclear Electronics Corp.....171
Nuclear Enterprises, Ltd.....176
Nuclear Instrument and Chemical Corp.....165
Nuclear Measurements Corp.....174
Nuclear Metals, Inc.....177
Nucleonics.....21
Packard Instrument Co.....119
Penberthy Instrument Co.....131, 176
Pergamon Press.....141
Philadelphia Pump & Machinery Co. 47
Powell Co., Wm.....24
Pratt & Whitney Aircraft Div. of United Aircraft Corp.....154
Radiation Applications, Inc.....187
Radiation Counter Laboratories, Inc. 17
Radiation Instrument Co.....172
Radiological Service Co., Inc.....188
Ray Proof Corporation.....149
Republic Steel.....32
Resistance Products Co.....156
Robertshaw Fulton Controls Co.....41
Samples Machine Co., A. M.....172
Sams & Co., Inc., Howard W.....148
Searchlight Section.....180, 182–186
Shieldalloy Corp.....175
Special Screw Products Co., The....114
Stanat Mfg. Co., Inc.....129
Staplex Co.....133
St. Eloi Corp. Research Laboratories of Colorado, Inc.....130
Superior Tube Co.....30, 31
Sylvania Electric Products, Inc.....18
Technical Associates.....147
Technical Operations, Inc.....132, 179
Tracerlab, Inc.....22
U. S. Stoneware.....23
United States Radium Corp.....122
Universal Atomics Corp.....156
Victoreen Instrument Co.....153
Vitro Corp. of America.....173
Westinghouse Electric Corp.....45, 146
Westlake Plastics Co.....130
Where to Buy.....180
White Dental Mfg. Co., S. S.....144
Wiley & Sons, Inc., John.....140

CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.
EMPLOYMENT OPPORTUNITIES 180, 182–186
EQUIPMENT (Used or Surplus New)
For Sale.....180

This index is published as a service. Every care is taken to make it accurate, but NUCLEONICS assumes no responsibility for errors or omissions.

BAIRD ATOMIC

SCALERS

For Reliability in Research

TEN HUNDRED SERIES MULTISCALER

MODEL 101B RADIOACTIVITY RESEARCH SCALER

GLOW TUBE SCALER

From the newest Radioactivity Research Scaler to the now-famous Multiscaler, Baird-Atomic Scalers offer a complete choice of instruments; fourteen models to provide versatility for all types of research.

These Scalers coupled with other B-A quality instrumentation make available complete systems for handling all radioactivity measurement projects. Your inquiries regarding equipment for specific problems are invited.

TEN HUNDRED SERIES

The standard in scaler design . . . offered in eight models . . . all available as automatic Multiscalers. This series has been widely accepted by leading laboratories and is now considered an integral part of many reactor control panels.

RADIOACTIVITY RESEARCH SCALERS

Binary scaling for research, highlighted by the new Model 101B, with high-speed resolution and added scale factor for the latest techniques. This Scaler offers the same high degree of reliability that has made the Model 101M an industry-wide favorite in radioactivity research projects.

GLOW TUBE SCALERS

These general-purpose B-A Glow Tube Scalers offer a selection of four models with or without built-in high voltage supplies for combination with appropriate detection devices to provide extremely versatile and economical radioactivity counting systems.

See the latest in Radioactivity Instrumentation

BOOTH 319-1320
11th ANNUAL I.S.A. CONFERENCE AND EXHIBIT, NEW YORK

BOOTH 137
TRADE FAIR OF THE ATOMIC INDUSTRY, CHICAGO

SALES REPRESENTATIVES

ATOMIC ASSOCIATES, INC. — New York, N. Y. — Boston 73, Mass. — Philadelphia 36, Pa.
V. A. BROWN & ASSOCIATES — Alexandria, Va. — Branch Offices throughout Southeastern U. S.
KITTLESON COMPANY — Los Angeles 36, Calif. — San Francisco, Calif. — Albuquerque, N. M.
RON MERRITT COMPANY — Seattle, Wash.
H. E. RANSFORD COMPANY — Pittsburgh 19, Pa.
PACKARD INSTRUMENT COMPANY — La Grange, Ill.
CANADIAN MARCONI COMPANY, LTD. — Montreal, Toronto, Winnipeg, Vancouver, Halifax
OVERSEAS — Australia, Belgium, Denmark, France, India, Israel, Italy, Japan, Mexico, Norway, Sweden, Switzerland

BAIRD ATOMIC

Baird Associates — Atomic Instrument Co.

33 UNIVERSITY ROAD, CAMBRIDGE 38, MASS.

Honeywell control instrumentation for the first privately owned reactor, at North Carolina State College.

385-MEV cyclotron at Columbia University's Nevis laboratory is controlled from this panel.

Count on...

Instrumentation engineering by Honeywell for the right nuclear installation control

THE EFFECTIVENESS and safety of control for nuclear installation depends not only on choosing the right instrumentation, but also in applying this instrumentation correctly to the job.

From Honeywell, you can be sure of getting both. A staff of application engineers well versed in the technology and requirements of nuclear projects goes to work on your problems. These men have worked in intimate contact with government and university research installations and with reactor manufacturers, ever since the initiation of the atomic energy program. They have full security clearance for classified work. Their contributions to control design have materially aided most of the important military and private industry projects.

A complete line of specialized instrumentation is at your command . . . including equipment for detection of radiation, for measurement of power level, for temperatures, and for measurement and control of the critical variables encountered in research, pilot operations and production. Your nearby Honeywell sales engineer is well qualified to consult on the requirements of your specific installation. Call him today . . . he's as near as your phone. MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Avenues, Philadelphia 44, Pa.—in Canada, Toronto 17, Ontario.

MINNEAPOLIS **Honeywell**

BROWN INSTRUMENTS

First in Controls

Write for Honeywell's Nuclear Reactor Control Booklet.